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(54) **APPARATUS AND METHODS FOR  
STABILIZATION AND VIBRATION  
REDUCTION**

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See application file for complete search history.

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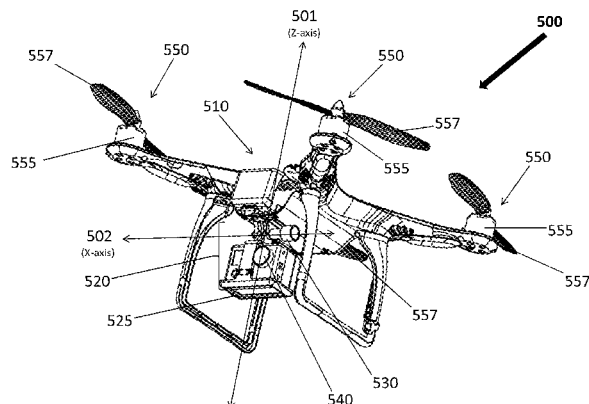
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(57) **ABSTRACT**

The present invention provides an apparatus for stabilizing an  
imaging device and methods of using the same for a wide  
variety of applications including photography, video, and  
filming. Also provided are unmanned vehicles including  
aerial vehicles that contain the apparatus disclosed herein.

**23 Claims, 12 Drawing Sheets**



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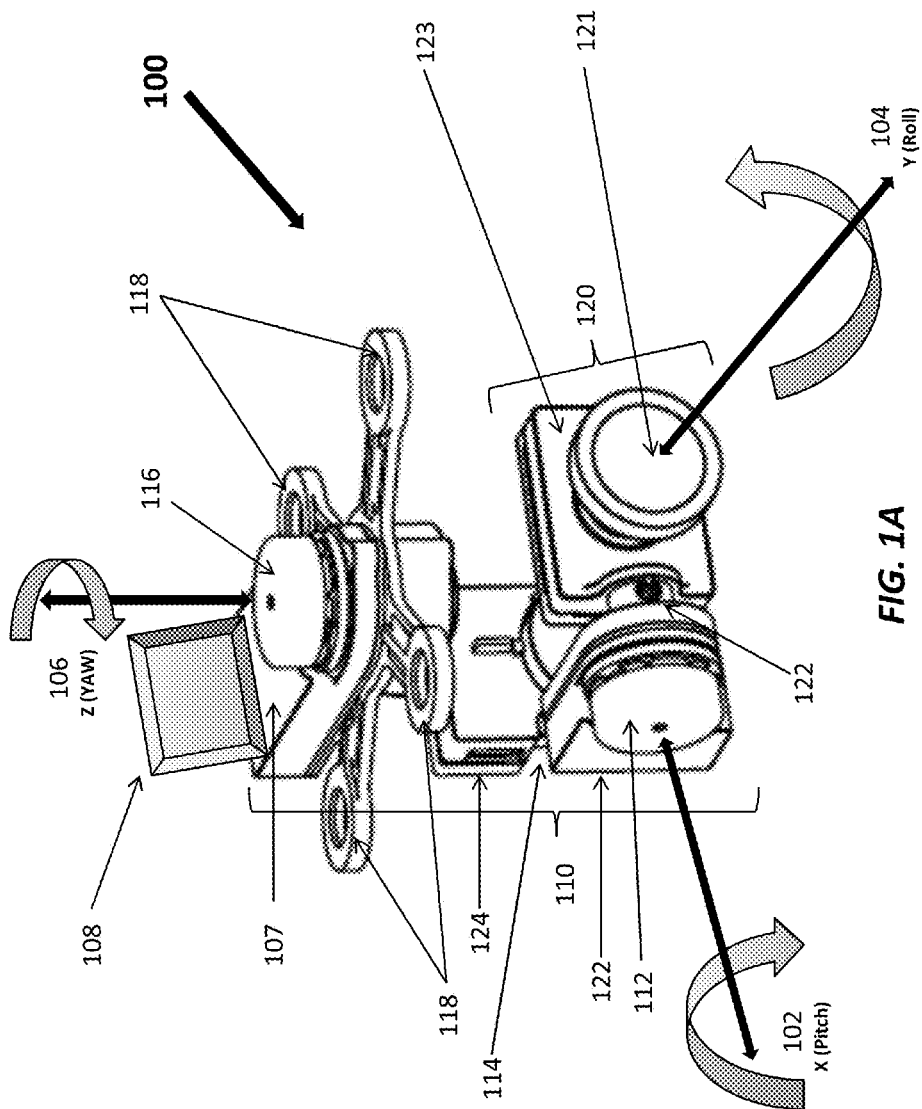
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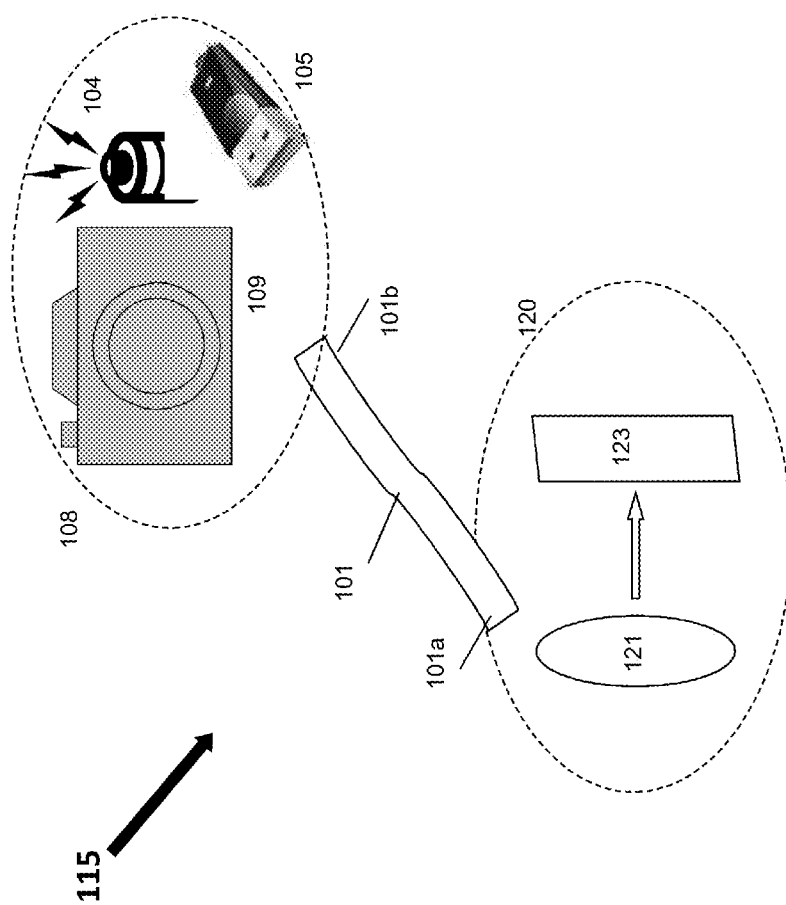


FIG. 1B

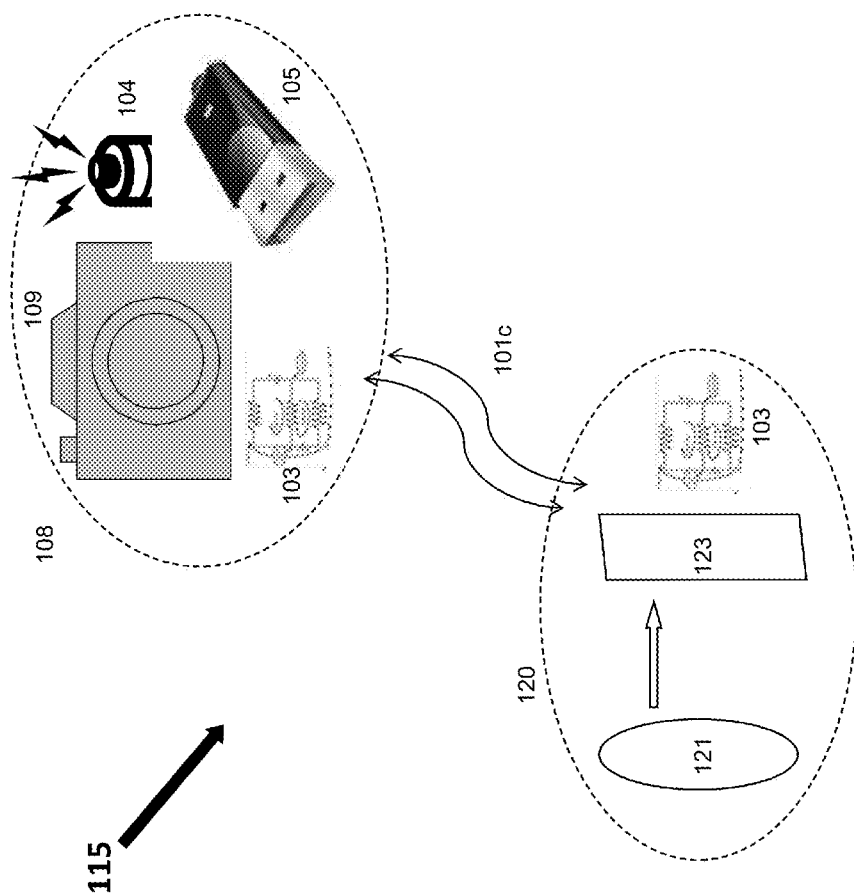
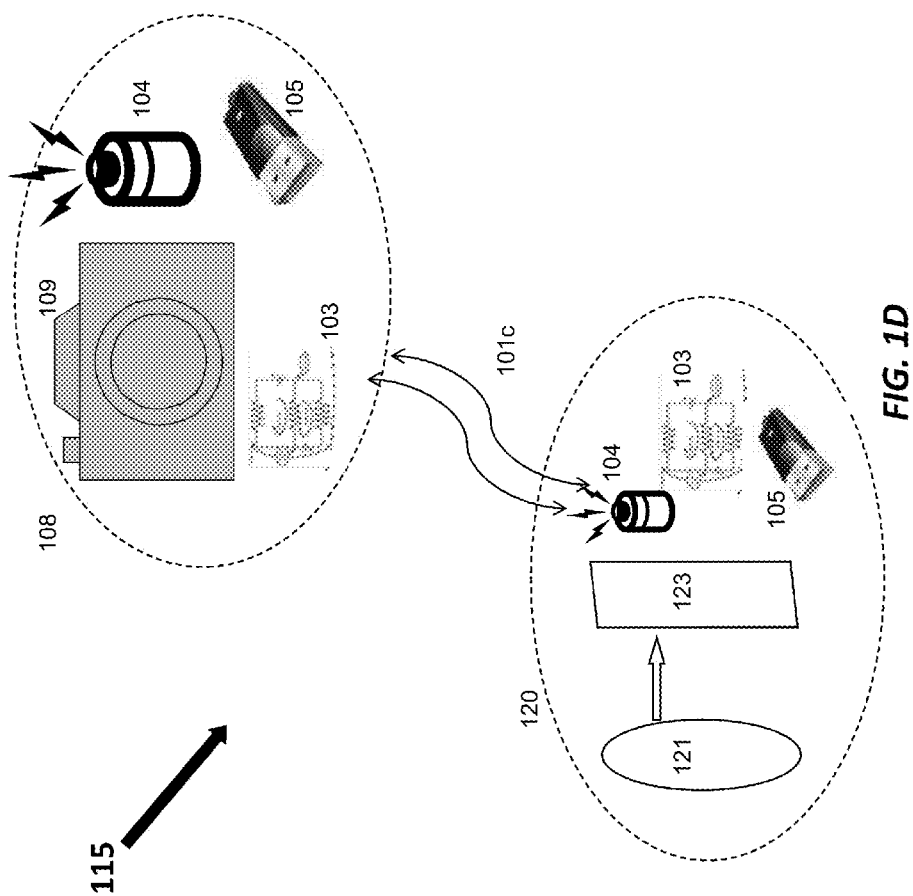
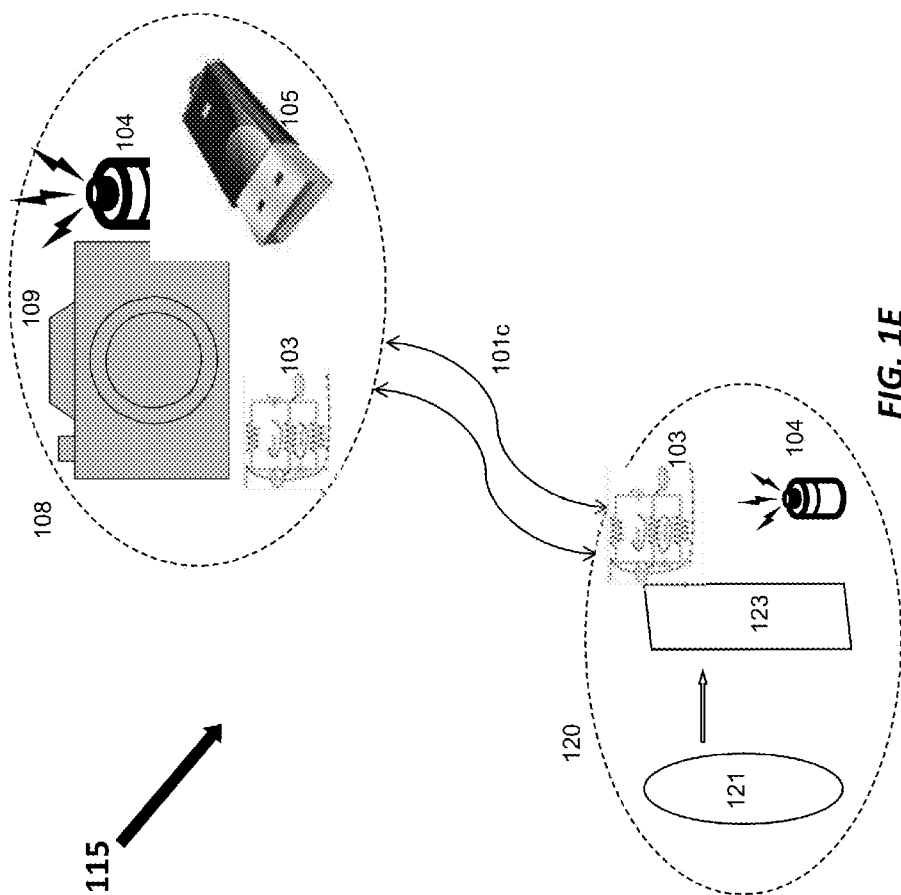


FIG. 1C





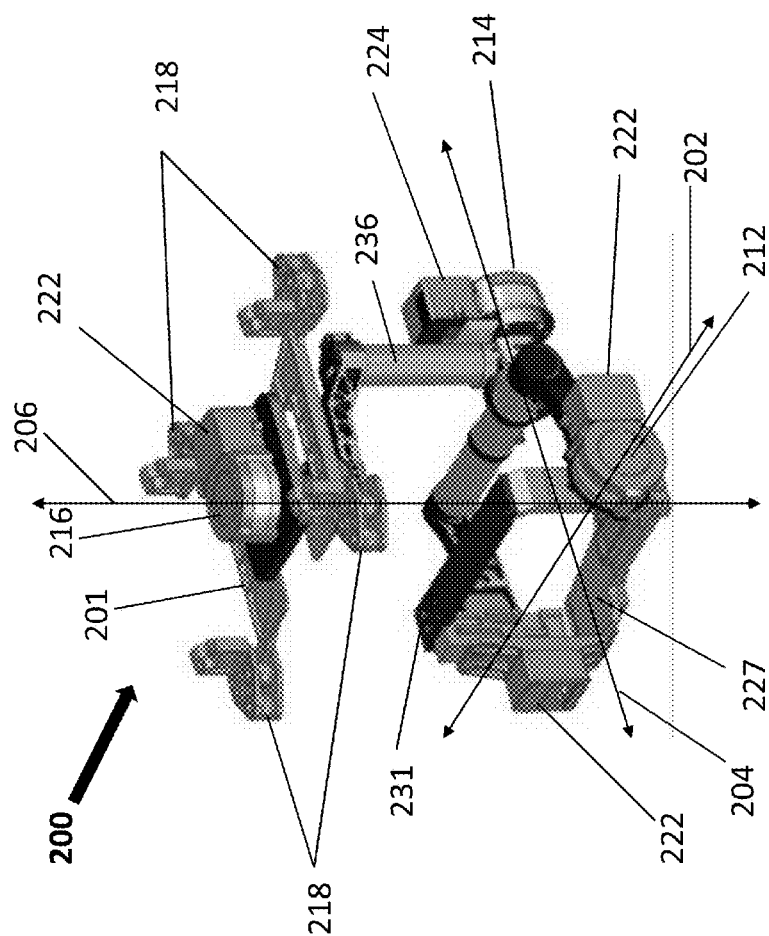


FIG. 2



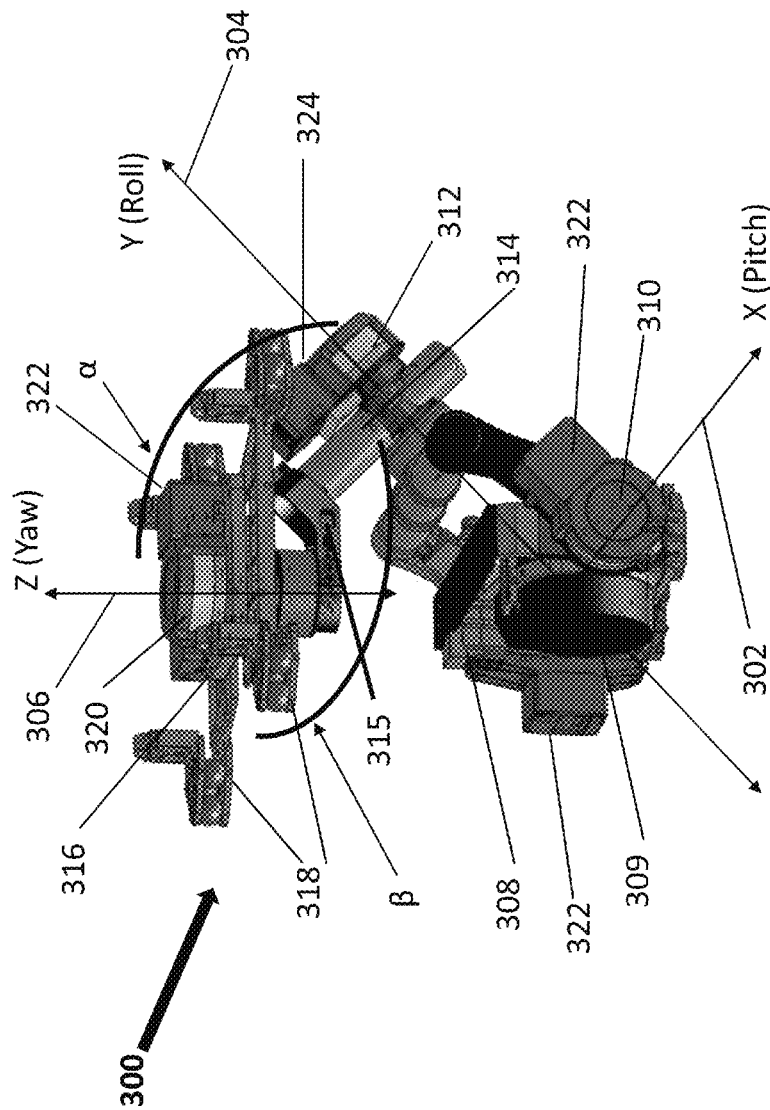


FIG. 3

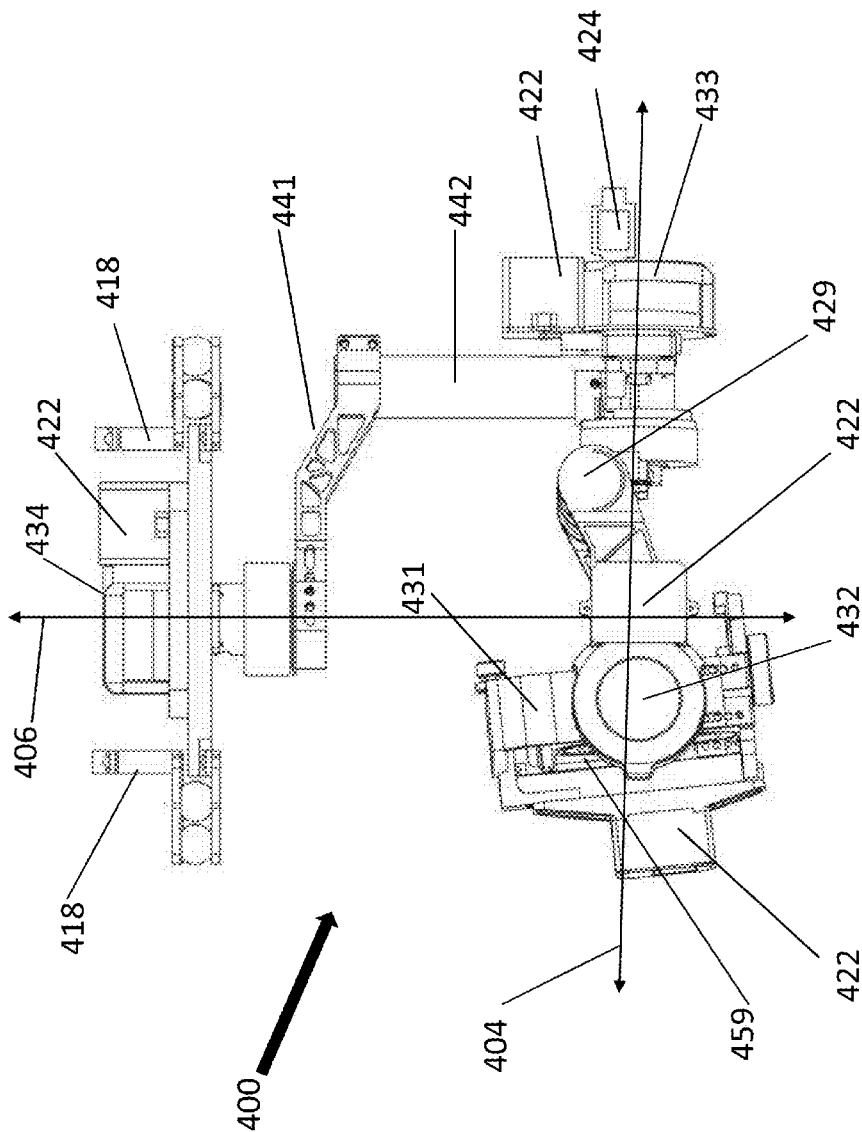
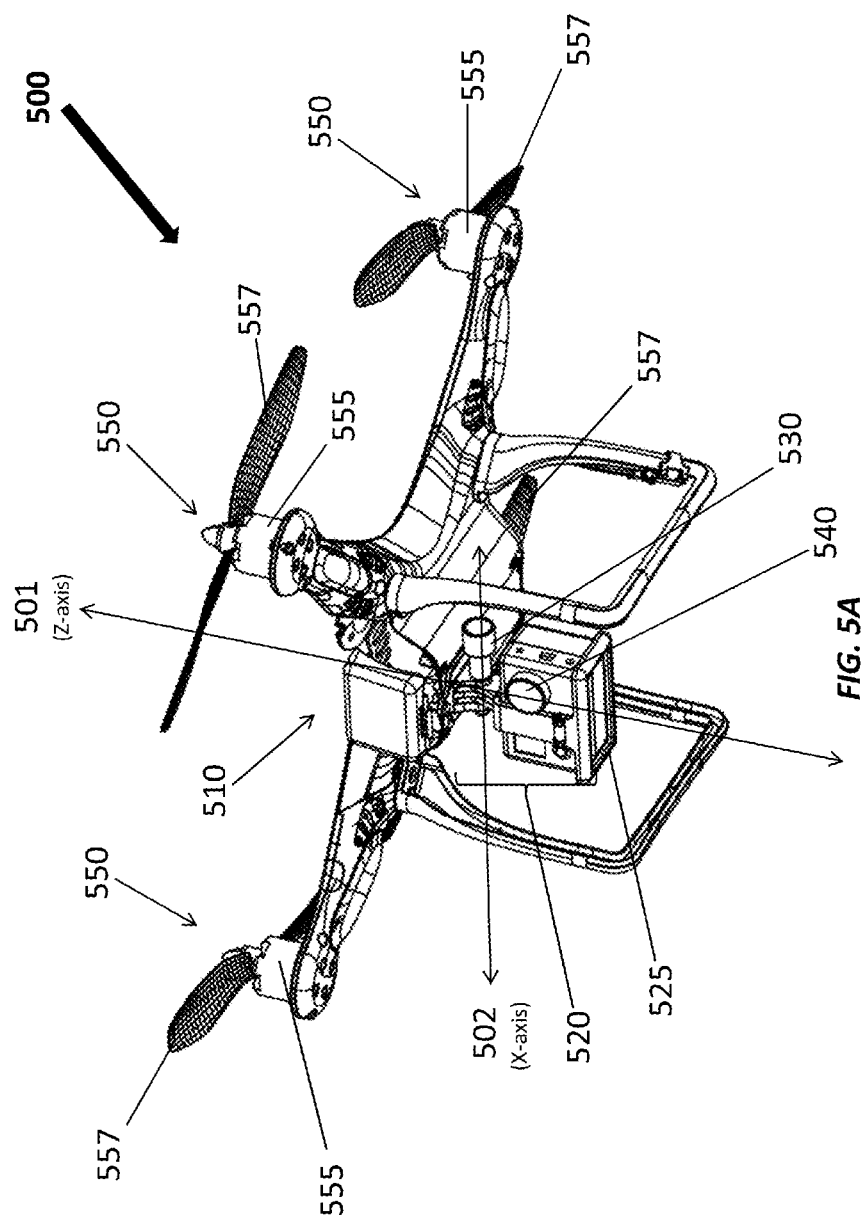


FIG. 4



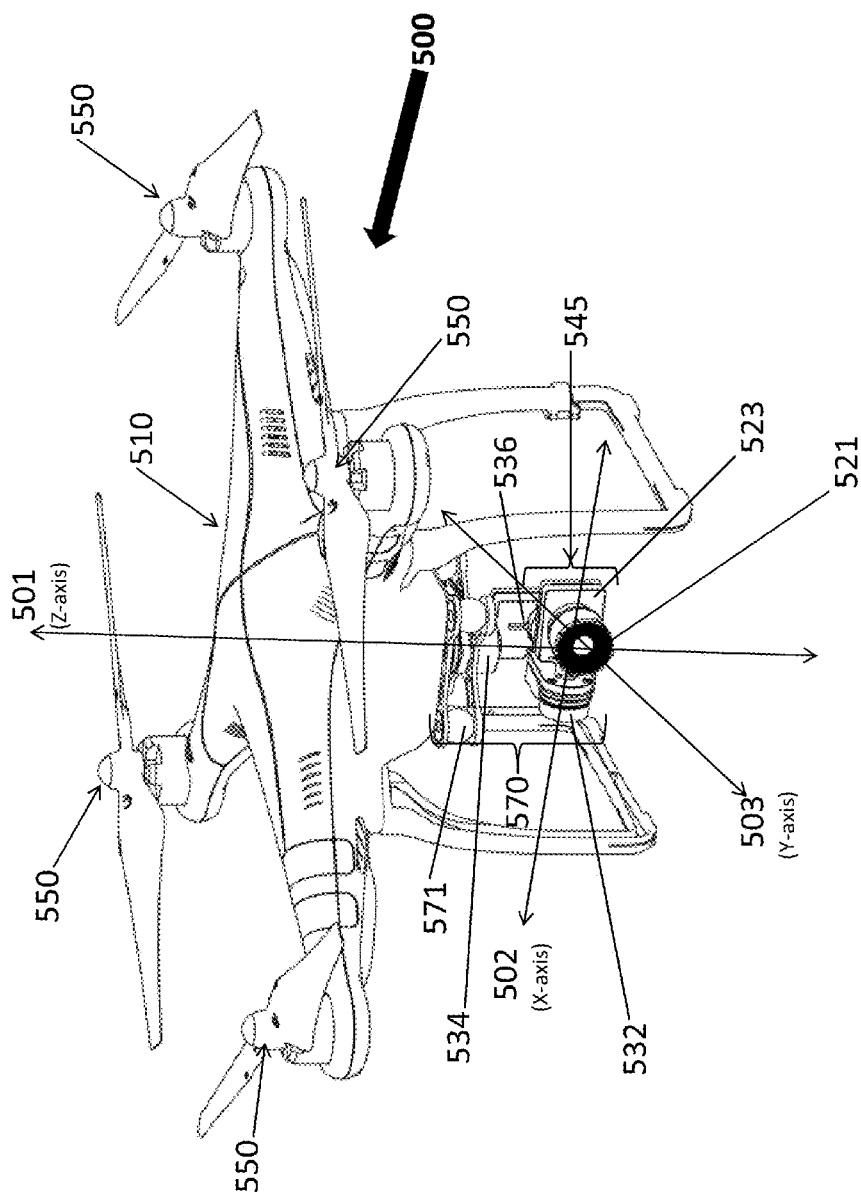


FIG. 5B

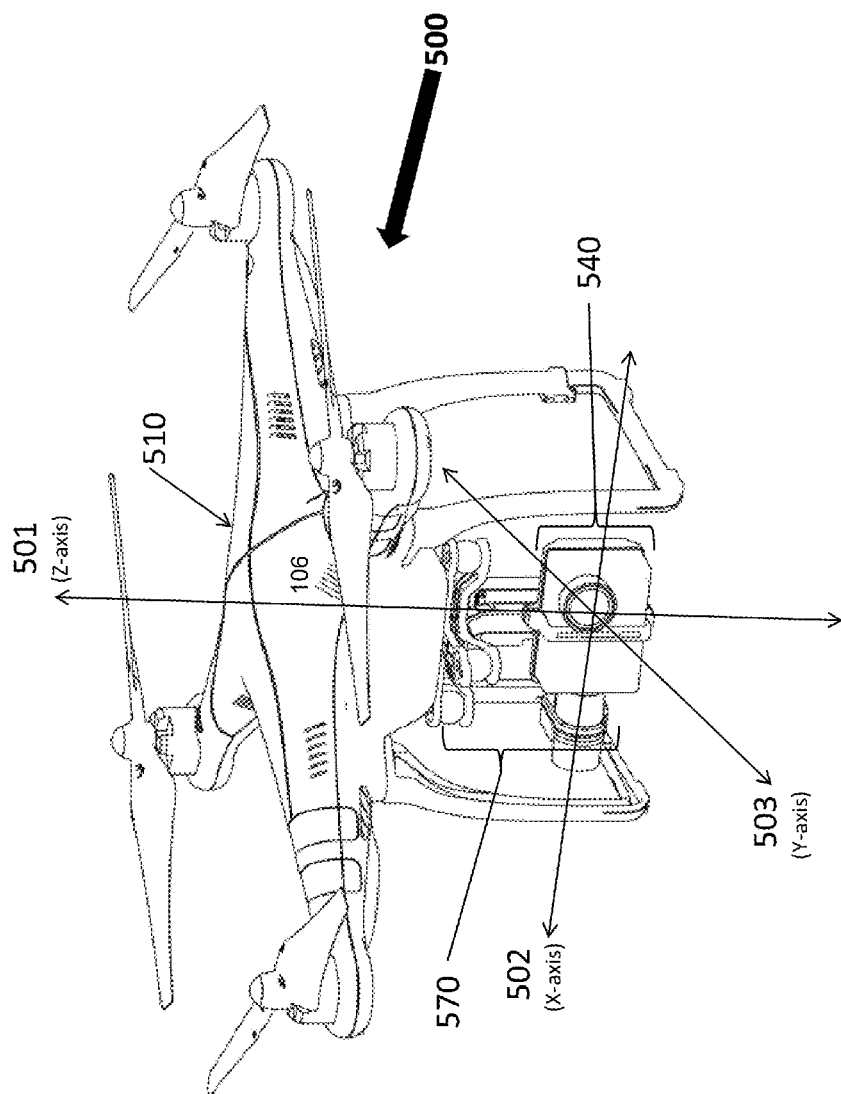


FIG. 5C

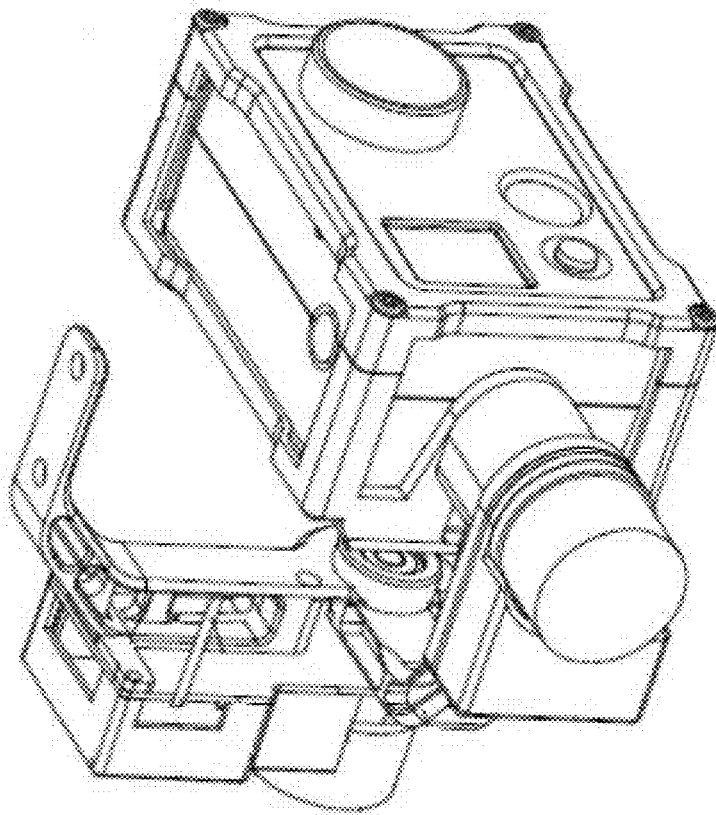


FIG. 6

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# APPARATUS AND METHODS FOR STABILIZATION AND VIBRATION REDUCTION

## CROSS-REFERENCE

This application is a continuation application of International Application No. PCT/CN2013/084857, filed on Oct. 8, 2013, the content of which is hereby incorporated in its entirety.

## BACKGROUND OF THE INVENTION

For many years, both amateur and professional photographers and videographers have struggled with blurred images due to instability of the camera mounting, motion by the user, motion and vibration transferred to the camera from a mobile transport, or some combination of these issues.

Currently, there exists primarily four methods of vibration dampening commonly employed in photography and videography to reduce the effects of vibration on the picture: software stabilization, lens stabilization, sensor stabilization, and overall shooting equipment stabilization.

Lens stabilization and sensor stabilization are now widely applied in many consumer digital cameras. The general principle of lens stabilization is to eliminate the shake on the lens by controlling horizontal displacement or rotation of a certain lens or some lenses; and sensor stabilization is intended to offset the vibration by enabling a photosensitive sensor to translate or rotate. Lens stabilization and sensor stabilization are both implemented within the shooting equipment, requiring minimal volume. However, due to structural limitations and limited travel range of the movement (including translation and rotation) of the lens or sensor, vibration with large amplitude or at high frequency is still difficult to eliminate completely, particularly when carrying the shooting equipment or mounting video equipment on a moving vehicle.

The effectiveness of software stabilization is limited. An extremely large amount of computation is required in the shake elimination process for video, often resulting in only a limited beneficial effect.

Overall, methods applied to shooting equipment stabilization mainly perform stabilization for the shooting equipment on three rotation axes, with a large rotation range and reasonably quick response. This can substantially overcome the drawbacks in lens stabilization and sensor stabilization. However, as stabilization is performed for the entire set of (video) equipment, the structure is usually quite large, making it inconvenient to carry or use, and requires very large amounts of energy (batteries) to drive the stabilizing equipment, making it inconvenient, impractical and relatively expensive for most commercial and personal applications.

## SUMMARY OF THE INVENTION

The present invention provides an alternative design for performing effective stabilization for a wide variety of applications including but not limited to still photo and video imaging. The present invention, embodies, in part, an apparatus and method of performing stabilization of an imaging device by, e.g., partitioning the optical unit from the non-optical unit of the imaging device. The present invention can substantially reduce the mass volume of the stabilizing device necessary to achieve such stabilization. This disclosed approach of stabilization i) reduces size and/or weight, ii) augments existing stabilization methods and/or, iii) facilitates

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miniaturization of the entire shooting equipment construct and any external stabilization structures used therewith.

In one aspect, the present invention provides an apparatus for stabilizing an imaging device comprising an optical unit and a non-optical unit, said optical unit and non-optical unit constituting the entire image device, said apparatus comprising: a frame assembly rotatably coupled to the optical unit of the imaging device, without supporting the entire imaging device as a whole, wherein the frame assembly configured to permit the optical unit to rotate about at least a first rotational axis and a second rotational axis, the optical unit comprising at least a lens and a photosensor that is optically coupled to the lens; and a motor assembly coupled to the frame assembly, the motor assembly configured to directly drive the frame assembly so as to permit the optical unit to rotate about at least the first rotational axis or the second rotational axis.

In some embodiments the non-optical unit of the imaging device is not mechanically coupled to the apparatus. In some embodiments the optical unit and the non-optical unit are electrically coupled. In some embodiments the optical unit and the non-optical unit are movable relative to each other.

In some embodiments, the non-optical unit of the imaging device is not mechanically coupled optical unit of the imaging device. In some embodiments, the optical unit and the non-optical unit communicate with each other wirelessly.

In some embodiments the optical unit of the imaging device further comprises at least one of a filter, positional sensor, storage medium, battery, zooming motor, circuitry, power supply, processor, or housing. In still other embodiments, the optical unit of the imaging device further comprises a weight adapted to provide stability for the optical unit. In still other embodiments, the weight comprises a battery.

In some embodiments, the non-optical unit does not include a lens or a photosensor. In other embodiments, the non-optical unit of the imaging device comprises at least one of a positional sensor, storage medium, battery, motors, circuitry, power supply, processor, or housing.

In some embodiments, at least one of the first rotational axis and the second rotational axis corresponds to a pitch, roll or yaw axis of the optical unit. In other embodiments, the frame assembly is further configured to permit the optical unit to rotate about a third rotational axis. In some embodiments, the third rotational axis corresponds to at least one of a pitch, roll, or yaw axis of the optical unit.

Still further, in some embodiments, the apparatus further comprises one or more positional sensors, wherein at least one of the one or more positional sensors is configured to detect state information associated with the optical unit. In addition the apparatus further comprises a controller for generating one or more motor signals based on the state information associated with the optical unit. In some embodiments, the state information comprises translational or rotational movement information or positional information.

In still other embodiments, at least one of the positional sensors is configured to detect state information associated with the non-optical unit.

In still further embodiments, at least one of the one or more positional sensors is configured to measure movement associated with at least a pitch, roll, or yaw axis of the optical unit. In addition, at least one of the one or more positional sensors comprises an inertial sensor.

In any of the preceding embodiments, the apparatus is configured to be coupled to a movable object. In addition, the apparatus is configured to reduce relatively more movement experienced by the optical unit caused by the movable object than the amount of movement experienced by the non-optical

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unit. In some embodiments, the apparatus for stabilizing an imaging device comprising an optical unit and a non-optical unit is configured to be handheld.

Still further, in any of the preceding embodiments, the frame assembly comprises a first stage connected to and supporting the optical unit, and a second stage movable relative to the first stage and the optical unit about the first rotational axis. In addition, the frame assembly can further comprise a third stage movable relative to the second stage about the second rotational axis.

Provided herein is an apparatus for stabilizing at least a portion of an imaging device that comprises an optical unit and a non-optical unit, said apparatus comprising a frame assembly having a volume that is less than that of a frame assembly required to support the entire imaging device having the optical unit and the non-optical unit, wherein the frame assembly is configured to support the optical unit of the imaging device, wherein the frame assembly is configured to permit rotation of the optical unit about at least a first rotational axis and a second rotational axis, and wherein the optical unit comprises at least a lens and a photosensor that is optically coupled to the lens; and wherein the motor assembly is configured to drive the frame assembly so as to permit rotation of the optical unit about at least the first rotational axis or the second rotational axis.

In some embodiments the non-optical unit of the imaging device is not mechanically coupled to the apparatus. In some embodiments the optical unit and the non-optical unit are electrically coupled. In some embodiments the optical unit and the non-optical unit are movable relative to each other.

In some embodiments, the non-optical unit of the imaging device is not mechanically coupled optical unit of the imaging device. In some embodiments, the optical unit and the non-optical unit communicate with each other wirelessly.

In some embodiments the optical unit of the imaging device further comprises at least one of a filter, positional sensor, storage medium, battery, zooming motor, circuitry, power supply, processor, or housing. In still other embodiments, the optical unit of the imaging device further comprises a weight adapted to provide stability for the optical unit. In still other embodiments, the weight comprises a battery.

In some embodiments, the non-optical unit does not include a lens or a photosensor. In other embodiments, the non-optical unit of the imaging device comprises at least one of a positional sensor, storage medium, battery, motors, circuitry, power supply, processor, or housing.

In some embodiments, at least one of the first rotational axis and the second rotational axis corresponds to a pitch, roll or yaw axis of the optical unit. In other embodiments, the frame assembly is further configured to permit the optical unit to rotate about a third rotational axis. In some embodiments, the third rotational axis corresponds to at least one of a pitch, roll, or yaw axis of the optical unit.

Still further, in some embodiments, the apparatus further comprises one or more positional sensors, wherein at least one of the one or more positional sensors is configured to detect state information associated with the optical unit. In addition the apparatus further comprises a controller for generating one or more motor signals based on the state information associated with the optical unit. In some embodiments, the state information comprises translational or rotational movement information or positional information.

In still other embodiments, at least one of the positional sensors is configured to detect state information associated with the non-optical unit.

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In still further embodiments, at least one of the one or more positional sensors is configured to measure movement associated with at least a pitch, roll, or yaw axis of the optical unit. In addition, at least one of the one or more positional sensors comprises an inertial sensor.

In any of the preceding embodiments, the apparatus is configured to be coupled to a movable object. In addition, the apparatus is configured to reduce relatively more movement experienced by the optical unit caused by the movable object than the amount of movement experienced by the non-optical unit. In some embodiments, the apparatus for stabilizing at least a portion of an imaging device comprising an optical unit and a non-optical unit is configured to be handheld.

Still further, in any of the preceding embodiments, the frame assembly comprises a first stage connected to and supporting the optical unit, and a second stage movable relative to the first stage and the optical unit about the first rotational axis. In addition, the frame assembly can further comprise a third stage movable relative to the second stage about the second rotational axis.

In another aspect, the present invention provides an apparatus for stabilizing at least a portion of an imaging device that comprises an optical unit and a non-optical unit, said optical unit and non-optical unit constituting the entire image device, said apparatus comprising: a frame assembly supporting the optical unit of the imaging device, wherein the frame assembly is configured to permit rotation of the optical unit about at least a first rotational axis and a second rotational axis, and wherein the optical unit comprises at least a lens and a photosensor that is optically coupled to the lens; and a motor assembly operably connected to the frame assembly, wherein the motor assembly is configured to drive the frame assembly so as to permit rotation of the optical unit about at least the first rotational axis or the second rotational axis, and wherein the motor assembly consumes a minimum amount of energy that is less than that required to drive a frame assembly supporting the entire imaging device.

In some embodiments the non-optical unit of the imaging device is not mechanically coupled to the apparatus. In some embodiments the optical unit and the non-optical unit are electrically coupled. In some embodiments the optical unit and the non-optical unit are movable relative to each other.

In some embodiments, the non-optical unit of the imaging device is not mechanically coupled optical unit of the imaging device. In some embodiments, the optical unit and the non-optical unit communicate with each other wirelessly.

In some embodiments the optical unit of the imaging device further comprises at least one of a filter, positional sensor, storage medium, battery, zooming motor, circuitry, power supply, processor, or housing. In still other embodiments, the optical unit of the imaging device further comprises a weight adapted to provide stability for the optical unit. In still other embodiments, the weight comprises a battery.

In some embodiments, the non-optical unit does not include a lens or a photosensor. In other embodiments, the non-optical unit of the imaging device comprises at least one of a positional sensor, storage medium, battery, motors, circuitry, power supply, processor, or housing.

In some embodiments, at least one of the first rotational axis and the second rotational axis corresponds to a pitch, roll or yaw axis of the optical unit. In other embodiments, the frame assembly is further configured to permit the optical unit to rotate about a third rotational axis. In some embodiments, the third rotational axis corresponds to at least one of a pitch, roll, or yaw axis of the optical unit.



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Still further, in some embodiments, the apparatus further comprises one or more positional sensors, wherein at least one of the one or more positional sensors is configured to detect state information associated with the optical unit. In addition the apparatus further comprises a controller for generating one or more motor signals based on the state information associated with the optical unit. In some embodiments, the state information comprises translational or rotational movement information or positional information.

In still other embodiments, at least one of the positional sensors is configured to detect state information associated with the non-optical unit.

In still further embodiments, at least one of the one or more positional sensors is configured to measure movement associated with at least a pitch, roll, or yaw axis of the optical unit. In addition, at least one of the one or more positional sensors comprises an inertial sensor.

In some of the preceding embodiments, the apparatus is configured to be coupled to a movable object. In addition, the apparatus is configured to reduce relatively more movement experienced by the optical unit caused by the movable object than the amount of movement experienced by the non-optical unit. In some embodiments, the apparatus for stabilizing at least a portion of an imaging device comprising an optical unit and a non-optical unit is configured to be handheld.

Still further, in some of the preceding embodiments, the frame assembly comprises a first stage connected to and supporting the optical unit, and a second stage movable relative to the first stage and the optical unit about the first rotational axis. In addition, the frame assembly can further comprise a third stage movable relative to the second stage about the second rotational axis.

In some embodiments of the apparatus, said energy is less than the amount of energy required to drive the frame assembly when the entire imaging device apparatus as a whole is supported by the frame assembly.

In some embodiments wherein an apparatus for stabilizing at least a portion of an imaging device that comprises an optical unit and a non-optical unit, and wherein the motor assembly consumes a minimum amount of energy that is less than that required to drive a frame assembly supporting the entire imaging device, said energy is less than the amount of energy required to drive the frame assembly when the entire imaging device apparatus as a whole is supported by the frame assembly.

In yet another aspect, the present invention provides an imaging device comprising an optical unit which comprises at least a lens and a photosensor that is optically coupled to the lens; and a non-optical unit that is electrically coupled to the optical unit, wherein the optical unit is movable relative to the non-optical unit via actuation of a frame assembly coupled to said optical unit.

In some embodiments, the non-optical unit is not mechanically coupled to the frame assembly.

In some embodiments, the optical unit further comprises at least one of a filter, positional sensor, storage medium, battery, zooming motor, circuitry, power supply, processor, or housing. In other embodiments, the optical unit further comprises a weight adapted to provide stability for the optical unit. In some embodiments the weight comprises a battery.

In some embodiments, the non-optical unit does not include a lens or a photosensor. In other embodiments, the non-optical unit of the imaging device comprises at least one of a positional sensor, storage medium, battery, motors, circuitry, power supply, processor, or housing.

In some embodiments of the imaging device, the optical unit is movable about a first rotational axis and a second

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rotational axis via the actuation of the frame assembly and the optical unit is movable about a third rotational axis via the actuation of the frame assembly.

In other embodiments of the imaging device, the optical unit is movable about a third rotational axis via the actuation of the frame assembly and the third rotational axis corresponds to at least one of a pitch, roll, or yaw axis of the optical unit.

In still further embodiments of the imaging device, the state information associated with the optical unit is detectable by one or more positional sensors and said state information associated with the optical unit is used to generate one or more motor signals that drive the actuation of the frame assembly. Said state information comprises translational or rotational movement information or positional information. In addition, state information associated with the non-optical unit is detectable by one or more positional sensors.

In still further embodiments of the imaging device, at least one of the one or more positional sensors is configured to measure movement associated with at least a pitch, roll, or yaw axis of the optical unit, and at least one of the one or more positional sensors comprises an inertial sensor.

In some embodiments, the frame assembly of the imaging device is configured to be coupled to a movable object.

In some embodiments of the imaging device, the optical unit and the non-optical unit are contained within a single housing. In other embodiments, the optical unit and the non-optical unit are not contained within a single housing.

In still other embodiments of the imaging device, the optical unit and the non-optical unit are both utilized to capture and store an image.

Provided herein is an aerial vehicle comprising a vehicle body, and attached thereto, an apparatus disclosed herein for stabilizing at least a portion of an imaging device. The apparatus attached to the vehicle comprises a frame assembly rotatably coupled to an optical unit of the imaging device, without supporting the entire imaging device as a whole, wherein the frame assembly is configured to permit the optical unit to rotate about at least a first rotational axis and a second rotational axis. Where desired, the optical unit comprises at least a lens and a photosensor that is optically coupled to the lens. The apparatus typically comprises a motor assembly coupled to the frame assembly, wherein the motor assembly is configured to directly drive the frame assembly so as to permit the optical unit to rotate about at least the first rotational axis or the second rotational axis.

In a separate aspect, the present invention provides an aerial vehicle comprising a vehicle body, and attached thereto, an apparatus disclosed herein for stabilizing at least a portion of an imaging device. The apparatus attached to the vehicle comprises a frame assembly having a volume that is less than that of a frame assembly required to support the entire imaging device with the optical and non-optical units, wherein the frame assembly is configured to permit the optical unit to rotate about at least a first rotational axis and a second rotational axis. Where desired, the optical unit comprises at least a lens and a photosensor that is optically coupled to the lens. The apparatus typically comprises a motor assembly coupled to the frame assembly, wherein the motor assembly is configured to directly or indirectly drive the frame assembly so as to permit the optical unit to rotate about at least the first rotational axis or the second rotational axis.

In still yet another embodiment, the present invention provides an aerial vehicle comprising a vehicle body, and attached thereto, an apparatus disclosed herein for stabilizing at least a portion of an imaging device. The apparatus attached

to the vehicle comprises a frame assembly supporting the optical unit of the imaging device, wherein the frame assembly is configured to permit rotation of the optical unit about at least a first rotational axis and a second rotational axis, and wherein the optical unit comprises at least a lens and a photosensor that is optically coupled to the lens. The apparatus typically comprises a motor assembly operably connected to the frame assembly, wherein the motor assembly is configured to drive the frame assembly so as to permit rotation of the optical unit about at least the first rotational axis or the second rotational axis, and wherein the motor assembly consumes a minimum amount of energy that is less than that required to drive a frame assembly supporting the entire imaging device.

In some embodiments of the aerial vehicle, said vehicle comprises an engine configured to drive movement of said aerial vehicle. In some embodiments, the engine is configured within said vehicle body.

In some embodiments, the aerial vehicle comprises one or more blades configured to rotate to provide lift to the unmanned aerial vehicle.

In some embodiments, the aerial vehicle is an unmanned aerial vehicle capable of controlled flight without requiring an occupant of the aerial vehicle.

In some embodiments of the aerial vehicle, the non-optical unit is supported by the vehicle body without being supported by the frame assembly.

Provided herein is a method of stabilizing at least a portion of an imaging device that comprises an optical unit and a non-optical unit, said method comprising: (1) supporting the optical unit of the imaging device using a frame assembly without supporting the entire imaging device as a whole, wherein the frame assembly is configured to permit rotation of the optical unit about at least a first rotational axis and a second rotational axis, and wherein the optical unit comprises at least a lens and a photosensor that is optically coupled to the lens; and (2) driving the frame assembly using a motor assembly operably connected to the frame assembly, thereby causing rotation of the optical unit about at least the first rotational axis or the second rotational axis.

In some embodiments of the stabilizing method, the optical unit and the non-optical unit are electrically coupled to each other.

In some embodiments of the stabilizing method, the optical unit further comprises at least one of a filter, positional sensor, storage medium, battery, zooming motor, circuitry, power supply, processor, or housing. In other embodiments of the method, the optical unit further comprises a weight adapted to provide stability for the optical unit. In some embodiments, the weight comprises a battery. In still further embodiments, the battery is configured to provide power necessary for operation of an aerial vehicle or the imaging device.

In some embodiments of the stabilizing method, the non-optical unit does not include a lens or a photosensor. In other embodiments of the stabilizing method, the non-optical unit comprises at least one of a positional sensor, storage medium, power supply, battery, motors, circuitry, display, processor, or housing.

In still other embodiments of the stabilizing method, at least one of the first rotational axis and the second rotational axis corresponds to a pitch, roll, or yaw axis of the optical unit. In other embodiments, the method further comprises driving the frame assembly using the motor assembly, thereby causing rotation of the optical unit about a third rotational axis. Still further the method wherein the third rotational axis corresponds to at least one of a pitch, roll or yaw axis of the optical unit.

In yet other embodiments of the stabilizing method, said method comprises receiving a signal from at least one positional sensor for indicative of an inclination angle of the non-optical unit and/or the optical unit in order to correct an inclination angle of the optical unit. In still other embodiments, said method further comprises reducing more movement experienced by the optical unit than the amount of movement experienced by the non-optical unit. In some embodiments of the method, said movement comprises at least one of vibration, shock, sway, tremor, shaking, or jerking movement.

In any of the preceding embodiments of the stabilizing method, said method further comprises capturing and storing an image using both the optical unit and non-optical unit.

Provided herein is a method of stabilizing at least a portion of an imaging device that comprises an optical unit and a non-optical unit, said optical unit and non-optical unit constituting the entire imaging device, said method comprising: supporting the optical unit of the imaging device using a frame assembly, the frame assembly having a volume that is less than that of a frame assembly required to support the entire imaging device having the optical unit and the non-optical unit, wherein the frame assembly is configured to permit rotation of the optical unit about at least a first rotational axis and a second rotational axis, and wherein the optical unit comprises at least a lens and a photosensor that is optically coupled to the lens; and driving the frame assembly using a motor assembly operably connected to the frame assembly, thereby causing rotation of the optical unit about at least the first rotational axis or the second rotational axis.

In some embodiments of the stabilizing method, the optical unit and the non-optical unit are electrically coupled to each other.

In some embodiments of the stabilizing method, the optical unit further comprises at least one of a filter, positional sensor, storage medium, battery, zooming motor, circuitry, power supply, processor, or housing. In other embodiments of the method, the optical unit further comprises a weight adapted to provide stability for the optical unit. In some embodiments, the weight comprises a battery. In still further embodiments, the battery is configured to provide power necessary for operation of an aerial vehicle or the imaging device.

In some embodiments of the stabilizing method, the non-optical unit does not include a lens or a photosensor. In other embodiments of the stabilizing method, the non-optical unit comprises at least one of a positional sensor, storage medium, power supply, battery, motors, circuitry, display, processor, or housing.

In still other embodiments of the stabilizing method, at least one of the first rotational axis and the second rotational axis corresponds to a pitch, roll, or yaw axis of the optical unit. In other embodiments, the method further comprises driving the frame assembly using the motor assembly, thereby causing rotation of the optical unit about a third rotational axis. Still further the method wherein the third rotational axis corresponds to at least one of a pitch, roll or yaw axis of the optical unit.

In yet other embodiments of the stabilizing method, said method comprises receiving a signal from at least one positional sensor for indicative of an inclination angle of the non-optical unit and/or the optical unit in order to correct an inclination angle of the optical unit. In still other embodiments, said method further comprises reducing more movement experienced by the optical unit than the amount of movement experienced by the non-optical unit. In some

embodiments of the method, said movement comprises at least one of vibration, shock, sway, tremor, shaking, or jerking movement.

In any of the preceding embodiments of the stabilizing method, said method further comprises capturing and storing an image using both the optical unit and non-optical unit.

Provided herein is a method of stabilizing at least a portion of an imaging device that comprises an optical unit and a non-optical unit, said method comprising: supporting the optical unit of the imaging device using a frame assembly, wherein the frame assembly is configured to permit rotation of the optical unit about at least a first rotational axis and a second rotational axis, and wherein the optical unit comprises at least a lens and a photosensor that is optically coupled to the lens; and driving the frame assembly using a motor assembly operably connected to the frame assembly, the motor assembly consuming a minimum amount of energy that is less than that required to drive a frame assembly supporting the entire imaging device, thereby causing rotation of the optical unit about at least the first rotational axis or the second rotational axis.

In some embodiments of the stabilizing method, the optical unit and the non-optical unit are electrically coupled to each other.

In some embodiments of the stabilizing method, the optical unit further comprises at least one of a filter, positional sensor, storage medium, battery, zooming motor, circuitry, power supply, processor, or housing. In other embodiments of the method, the optical unit further comprises a weight adapted to provide stability for the optical unit. In some embodiments, the weight comprises a battery. In still further embodiments, the battery is configured to provide power necessary for operation of an aerial vehicle or the imaging device.

In some embodiments of the stabilizing method, the non-optical unit does not include a lens or a photosensor. In other embodiments of the stabilizing method, the non-optical unit comprises at least one of a positional sensor, storage medium, power supply, battery, motors, circuitry, display, processor, or housing.

In still other embodiments of the stabilizing method, at least one of the first rotational axis and the second rotational axis corresponds to a pitch, roll, or yaw axis of the optical unit. In other embodiments, the method further comprises driving the frame assembly using the motor assembly, thereby causing rotation of the optical unit about a third rotational axis. Still further the method wherein the third rotational axis corresponds to at least one of a pitch, roll or yaw axis of the optical unit.

In yet other embodiments of the stabilizing method, said method comprises receiving a signal from at least one positional sensor for indicative of an inclination angle of the non-optical unit and/or the optical unit in order to correct an inclination angle of the optical unit. In still other embodiments, said method further comprises reducing more movement experienced by the optical unit than the amount of movement experienced by the non-optical unit. In some embodiments of the method, said movement comprises at least one of vibration, shock, sway, tremor, shaking, or jerking movement.

In any of the preceding embodiments of the stabilizing method, said method further comprises capturing and storing an image using both the optical unit and non-optical unit.

Provided herein is a method of stabilizing at least a portion of an imaging device, said method comprising providing an optical unit comprising at least a lens and a photosensor that is optically coupled to the lens; electrically coupling a non-optical unit to the optical unit; and moving the optical unit

relative to the non-optical unit via actuation of a frame assembly coupled to said optical unit.

In some embodiments of the stabilizing method, the optical unit further comprises at least one of a filter, positional sensor, storage medium, battery, zooming motor, circuitry, power supply, processor, or housing. In other embodiments of the method, the optical unit further comprises a weight adapted to provide stability for the optical unit. In some embodiments, the weight comprises a battery. In still further embodiments, the battery is configured to provide power necessary for operation of an aerial vehicle or the imaging device.

In some embodiments of the stabilizing method, the non-optical unit does not include a lens or a photosensor. In other embodiments of the stabilizing method, the non-optical unit comprises at least one of a positional sensor, storage medium, power supply, battery, motors, circuitry, display, processor, or housing.

In still other embodiments of the stabilizing method, at least one of the first rotational axis and the second rotational axis corresponds to a pitch, roll, or yaw axis of the optical unit. In other embodiments, the method further comprises driving the frame assembly using the motor assembly, thereby causing rotation of the optical unit about a third rotational axis. Still further the method wherein the third rotational axis corresponds to at least one of a pitch, roll or yaw axis of the optical unit.

In yet other embodiments of the stabilizing method, said method comprises receiving a signal from at least one positional sensor for indicative of an inclination angle of the non-optical unit and/or the optical unit in order to correct an inclination angle of the optical unit. In still other embodiments, said method further comprises reducing more movement experienced by the optical unit than the amount of movement experienced by the non-optical unit. In some embodiments of the method, said movement comprises at least one of vibration, shock, sway, tremor, shaking, or jerking movement.

In any of the preceding embodiments of the stabilizing method, said method further comprises capturing and storing an image using both the optical unit and non-optical unit.

Provided herein is an aerial vehicle comprising a vehicle body and a frame assembly connected to said vehicle body, wherein said frame assembly comprises a battery attached thereto and said frame assembly is configured to hold and stabilize an imaging device having an optical unit, and wherein the battery is attached to the assembly at a location separate from that of the imaging device, and wherein the battery is configured to provide power for operation of the aerial vehicle or the imaging device.

In some embodiments, the battery is configured to provide power for operation of the aerial vehicle. In some embodiments the battery has a weight that provides stability to said optical unit of said imaging device.

#### INCORPORATION BY REFERENCE

All publications, patents, and patent applications mentioned in this specification are herein incorporated by reference to the same extent as if each individual publication, patent, or patent application was specifically and individually indicated to be incorporated by reference.

#### BRIEF DESCRIPTION OF THE DRAWINGS

The novel features of the invention are set forth with particularity in the appended claims. A better understanding of the features and advantages of the present invention will be

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obtained by reference to the following detailed description that sets forth illustrative embodiments, in which the principles of the invention are utilized, and the accompanying drawings of which:

FIG. 1A is an illustrative isometric view of an exemplary stabilizing apparatus assembly.

FIGS. 1B-1E are illustrative arrangements of optical and non-optical assemblies of imaging devices.

FIG. 2 is an illustrative isometric view of an exemplary 3-axis stabilizing apparatus assembly

FIG. 3 is an illustrative isometric view of an exemplary non-orthogonal 3-axis stabilizing apparatus assembly with an optical unit.

FIG. 4 is a side view of FIG. 2 illustrating an exemplary orthogonal 3-axis stabilizing apparatus assembly with an optical unit.

FIG. 5A is an illustrative ISO view of an exemplary aerial vehicle with a 2-axis stabilizing apparatus assembly comprising an imaging device mounted on the frame.

FIG. 5B is an illustrative ISO view of an exemplary aerial vehicle with a 3-axis stabilizing apparatus assembly supporting the optical unit an imaging device mounted on the frame.

FIG. 5C is an illustrative ISO view of an exemplary aerial vehicle with a 3-axis stabilizing apparatus assembly supporting an entire imaging device mounted on the frame.

FIG. 6 is an illustrative view of an exemplary 2-axis stabilizing frame assembly an entire imaging device.

#### DETAILED DESCRIPTION OF THE INVENTION

Apparatus and methods have been developed to reduce the effects of vibration and allow for the size reduction of stabilization equipment for photography and videography, by separating the components of the imaging device, reducing the relative mass of all components involved, and focusing the majority of the stabilization efforts near the optics components of the imaging device.

The apparatus incorporates the use of positional sensors wherein a positional sensor shall mean: motion sensors (accelerometers) and rotation sensors (gyroscopes) or other inertial sensors to continuously calculate via dead reckoning the position, orientation, and velocity (direction and speed of movement) of a moving object without the need for external references"; e.g.: "state information". Positional sensors shall also include sensors that use external references such as compasses, and GPS (global positioning system) sensors, and the like.

In addition, the apparatus incorporates controllers for generating one or more motor signals for driving the movement of the frame assembly of the apparatus, based on the state information generated by the sensors.

An apparatus for stabilizing at least a portion of an imaging device has been developed. The imaging device comprises an optical unit and a non-optical unit. The apparatus comprises a frame assembly rotatably coupled to the optical unit of the imaging device, wherein said frame is configured to permit the optical unit to rotate about at least a first rotational axis and a second rotational axis, the optical unit comprising at least a lens and a photosensor. Said apparatus comprising a frame assembly having a volume that is less than that of a frame assembly required to support the entire imaging device having the optical unit and the non-optical unit. In one embodiment, said frame assembly will have a volume that is no more than one half of that of a frame assembly required to support the entire imaging device. Said apparatus also having a motor assembly wherein the motor assembly consumes a

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minimum amount of energy that is less than that required to drive a frame assembly supporting the entire imaging device. In a preferred embodiment, said motor assembly will consume no more than one half of the amount of energy than that of a motor assembly required to drive a frame assembly supporting the entire imaging device. Said apparatus can be configured to be coupled to a moving vehicle, an aerial vehicle, or can be handheld.

Provided herein, as shown in FIG. 1A, is an exemplary apparatus 100 for stabilizing an imaging device 115, (108+120) comprising an optical unit 120 and a non-optical unit 108, said apparatus comprising: a frame assembly 110 rotatably coupled to the optical unit 120 of the imaging device, without supporting the entire imaging device as a whole 115, wherein the frame assembly 110 configured to permit the optical unit 120 to rotate about at least a first rotational axis 102 and a second rotational axis 104, the optical unit 120 comprising at least a lens 121 and a photosensor 123 that is optically coupled to the lens; and a motor assembly 112, 114 coupled to the frame assembly 110, the motor assembly configured to directly drive the frame assembly so as to permit the optical unit to rotate about at least the first rotational axis 102 or the second rotational axis 104. As shown, the non-optical unit is coupled to the frame assembly on a base 107, which can be on a completely different part of the frame, or even a remote location.

As a further illustration, FIG. 1B illustrates one possible configuration of an imaging device 115, wherein the optical unit 120 and the non-optical unit 108 are physically separated, but coupled by optical cabling 101 or wiring, and electrically coupled at each end 101a, and 101b. In this illustration, the non-optical unit is comprises a housing 109, a battery 104 and storage media 105. The optical unit 120 comprises a lens 121, and a photosensor 123.

In some embodiments the non-optical unit 108 of the imaging device is not mechanically coupled to the apparatus. It is understandable that once one realizes that the components of the imaging device can be physically separated, it is no longer necessary for both components to be physically located on the same apparatus. For example, the optical unit 120 may be located on the apparatus, while the non-optical unit 120 is located somewhere else, preferably nearby, but not necessarily. In some embodiments the optical unit and the non-optical unit are electrically coupled (FIG. 1B). This may typically be accomplished by optical cabling or electrical wiring 101. In some embodiments the optical unit and the non-optical unit are movable relative to each other. As shown in FIG. 1 and further illustrated in FIG. 1B, when the optical unit and non-optical unit are physically separated, and physically located on separate mounting bases, and/or separate axes of a multi-axis apparatus, such as described herein, the optical unit and non-optical unit can be configured to each other, by design.

In some embodiments, the non-optical unit of the imaging device is not mechanically coupled to the optical unit of the imaging device, as illustrated in FIGS. 1C 1E by other means including but not limited to wireless 101c communication between the optical unit and the non-optical unit. Such wireless means of communication include electromagnetic telecommunications, (i.e.: radio), and point-to-point, or point-to-multi-point wireless networking, or alternately, light (e.g.: infrared), magnetic, or electric fields.

In some embodiments, such as illustrated in FIGS. 1C 1E, the optical unit 120 of the imaging device 115 further comprises at least one of a filter (not shown), positional sensor (not shown), storage medium 105, battery 104, zooming motor (not shown), circuitry 103, power supply (alternately 104), processor (not shown), or housing (not shown).

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Because the major components of the imaging device have been separated for this apparatus, it may be necessary to individually configure each major component with various sub-components, which may or may not be redundant to the other major component(s). Examples may include; positional sensors, storage media **105**, a source of power **104**, etc. Alternatively, some components will rarely if ever be needed in all major components. In still other embodiments, the optical unit of the imaging device further comprises a weight adapted to provide stability for the optical unit. Depending on the application and physical density, any number of sub-components may act in the dual capacity of a weight and their alternate, intended function. For example, in some embodiments, the weight may comprise a battery **104**.

In some embodiments, the non-optical **108** unit does not include a lens **121**, or a photosensor **123**, as illustrated in FIGS. **1B-1E**. In other embodiments, the non-optical unit of the imaging device comprises at least one of a positional sensor (not shown), storage medium **105**, battery **104**, motors (not shown), circuitry **103**, power supply, processor (not shown), or housing **109**.

In some embodiments, at least one of the first rotational axis **102** and the second rotational axis **104** corresponds to a pitch, roll or yaw axis of the optical unit. In other embodiments, the frame assembly is further configured to permit the optical unit to rotate about a third rotational axis **106**. In some embodiments, the third rotational axis corresponds to at least one of a pitch, roll, or yaw axis of the optical unit. Although specific axes of rotation have been illustrated in FIG. **1**, one of skill in the art would recognize that the axes of rotation can be randomly substituted, as appropriate, to meet the needs of a given application; meaning X-axis (pitch) rotation can be substituted with Y-axis (roll) rotation, or Z-axis (yaw) rotation can be substituted with X-axis (pitch) rotation, etc.

Still further, in some embodiments, the apparatus further comprises one or more positional sensors **122**, wherein at least one of the one or more positional sensors is configured to detect state information associated with the optical unit **120**. In addition the apparatus further comprises a controller for generating one or more motor signals **124** based on the state information associated with the optical unit. In some embodiments, the state information comprises translational or rotational movement information or positional information.

In still other embodiments, at least one of the positional sensors is configured to detect state information associated with the non-optical unit. This is useful for orienting the image generated by the imaging device in space, e.g., especially when the non-optical unit is mounted on a base (e.g.: **107**) that may represent the horizontal or vertical axis of a carrier device.

In still further embodiments, at least one of the one or more positional sensors is configured to measure movement associated with at least a pitch, roll, or yaw axis of the optical unit. In addition, at least one of the one or more positional sensors comprises an inertial sensor.

In any one of the preferred embodiments as illustrated in FIGS. **2, 3, 4**, the rotational (pitch) axis **X 202** of the first frame member mounting base **227** is orthogonally disposed relative to the rotational (roll) axis **Y 204**, for example, to allow the motors to easily and timely adjust the rotation of the frame assembly. In other embodiments, the rotational axes may not be orthogonally disposed to each other such as in FIG. **3**.

In some embodiments, as illustrated in FIG. **4**, the rotational (roll) axis **X 404** is orthogonally disposed relative to the rotational (yaw) axis **Y 406**, for example, to allow the motors to easily and timely adjust the rotation of the frame assembly.

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In other embodiments, the rotational axes may not be orthogonally disposed to each other such as in FIG. **3**.

To further increase the stability for the payload device, the center of gravity of the first frame member mounting base **308** and the payload device **309** as a whole is preferably located on the rotational (pitch) axis **X 302** of the first frame member, as illustrated in FIG. **3**. In some embodiments, the pitch axis intersects with the payload device **309**. It is appreciated that when the center of gravity of the first frame member and the payload device **309** is positioned on the rotational axis **X 302** of the first frame member, the rotation of the first frame member does not generate any torque. In other words, the first frame member is not likely to have any swing movement caused by the torque. Thus, the stability of the payload device is enhanced during rotation. In addition, in the preferred embodiment, when the carrier is moving smoothly, that is, when little or no motor drive stabilization is required, the first frame member and the payload device **309** is also in a dynamically balanced state.

Similarly, to provide enhanced stability and avoid torque generated by rotation around the rotational **Y (roll) axis 304**, in a preferred embodiment and as shown in FIG. **3**, the center of gravity of the first frame member, the second frame member and the payload device **309** as a whole is located on the rotational axis **Y 304** of the second frame member. In some embodiments, the rotational **Y (roll) axis 304** intersects with the payload device **309**.

It is also appreciated that in the aforementioned configuration of the frame assembly can provide near limitless ranges of motion for axes 1, 2, or 3, allowing for rotational swings of **X, Y or Z axes**, individually or together, in ranges from **0-360 degrees** or more, allowing the payload device **309** to circumferentially rotate (e.g., up to **360 degrees, 720 degrees**, or more, in any axis), for example, in order to perform panoramic photography.

In any of the preceding and subsequent embodiments, the apparatus can be configured to be coupled to a movable object. In some embodiments, the fixing points **118, 218, 318, 418** may be used to mount the mounting base **201** to or to facilitate the carrying of the stabilizing platform by a carrier, such as an aerial vehicle, motor vehicle, ship, robot, human, or any other movable object. As another example, the mounting base **201** may be handheld by a human, for example, to perform dynamic videography or photography.

A moveable object may be anything that can move relative to the earth. For example, moveable objects can be a wheeled-vehicle; a tracked-vehicle; a sliding or sledged vehicle; an aircraft; a hovercraft; a watercraft; or a spacecraft. Alternatively, a moving object can be a human being; a mammal; an aquatic animal; an amphibious animal; a reptile; a bird; or an invertebrate animal. Still further, a moving object can be relatively fixed, but still capable of movement, such as a tree, pole, or even a building that may be subject to swaying or vibration due to wind or even earthquakes.

In addition, the apparatus is configured to reduce relatively more movement experienced by the optical unit caused by the movable object than the amount of movement experienced by the non-optical unit. This movement can include but limit one of vibration, shock, sway, tremor, shaking, or jerking movement. In some embodiments, the apparatus for stabilizing an imaging device comprising an optical unit and a non-optical unit is configured to be handheld. Such apparatus can produce a more stable platform for vibration-resistant or even vibration-free imagery by, e.g., isolating the optical unit of an imaging device. Since a large proportion of the overall weight of an imaging device is associated with components and sub-components that are not directly associated with the lens

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and photosensor, the apparatus is designed to provide better vibration dampening and higher response rates to the smaller and lighter components of the optical unit alone.

Still further, as specifically illustrated in FIG. 1, or implied in any of the preceding or subsequent embodiments, the frame assembly comprises a first stage connected to and supporting the optical unit, a second stage movable relative to the first stage, and the optical unit about the first rotational axis. In addition, the frame assembly can further comprise a third stage movable relative to the second stage about the second rotational axis.

As further illustrated in FIG. 1, provided herein is an apparatus for stabilizing at least a portion of an imaging device that comprises an optical unit and a non-optical unit, said apparatus comprising a frame assembly having a volume that is less than that of a frame assembly required to support the entire imaging device having the optical unit and the non-optical unit as potentially illustrated in FIGS. 4 and 5B, wherein the frame assembly is configured to support the optical unit 120 of the imaging device, wherein the frame assembly is configured to permit rotation of the optical unit about at least a first rotational axis 102 and a second rotational axis 104, and wherein the optical unit comprises at least a lens 121 and a photosensor 123 that is optically coupled to the lens; and wherein the motor assembly 112 or 114 (not shown) is configured to drive the frame assembly 110 so as to permit rotation of the optical unit 120 about at least the first rotational axis 102 or the second rotational axis 104.

In some embodiments, a frame assembly has a volume that is preferably one half or less than that of a frame assembly required to support the entire imaging device. For example, miniaturized components of the optical unit, described herein, and illustrated in FIG. 1, have the following proportions, wherein a 1/2.33" photosensor having an imaging area of 6.13×4.6 mm, weighs 0.6 g. The entire optical unit (photosensor lens and structure used secure lens and photosensor), plus a three-axis gyroscope and three-axis accelerometer, weigh about 15 g. The overall dimensions would be approximately 2.5 cm×1.8 cm×3 cm. The non-optical unit of an imaging system designed to work with this optical unit would have the outer dimension volumes of 77 mm×67 mm×80 mm, and have a total weight of 80 g (excluding the optical component). In addition, the motor along each axis of a 3-axis frame assembly has a rated power of only about 2 w. The invention described herein compares very favorably to other successful "compact" imaging systems having a 1/2.33" photosensor such as one by GoPro®, wherein the dimensions are 58.4×38.1×20.3 mm and the weights are approximately 75 g. For stabilizing the whole GoPro camera, currently existing 2-axis platforms weigh 200 g (excluding the camera), with an outer dimensional volume of 93 mm×85 mm×100 mm. The much larger motors required to drive the larger frames require 5 w power levels for each motor along each axis.

By separating the optical unit from the non-optical unit, the volume of the frame assembly required for stabilization is less than that is required to support the entire imaging device. In some embodiment, the volume of the frame assembly is reduced by 10%, 20%, 30%, 40%, 50%, 60%, 70%, 100% or more as compared to the volume of a frame assembly for supporting the entire imaging device. In other embodiments, the volume of the frame assembly is merely 1/4, 1/3, 1/2, 3/4 or less of that is required for supporting the entire imaging device having the optical and non-optical units as a whole.

In other embodiment, the minimum amount of the energy required by a subject motor to drive the subject frame assembly is less than that is required to drive a frame assembly supporting the entire imaging device. In some embodiments,

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the motor consumes a minimum amount of energy that is 90%, 80%, 70%, 60%, 50%, 40%, 30%, 20%, 10% or even less than that which is required for a motor driving a frame assembly supporting the whole imaging device (e.g., with optical and the non-optical units as an integral piece). In some embodiments, the minimum amount of energy required by the subject motor is less than 5 W, 4 W, 3 W, 2 W, 1 W power to drive along an axis of a frame assembly.

In some embodiments the non-optical unit of the imaging device 115 is not mechanically coupled to the apparatus. In some embodiments the optical unit and the non-optical unit are electrically coupled. In some embodiments the optical unit and the non-optical unit are movable relative to each other. As shown in FIG. 1, when the optical unit and non-optical unit are physically separated, and physically located on separate mounting bases, and/or separate axes of a multi-axis apparatus, such as described herein, the optical unit and non-optical unit will move relative to each other, by design.

As previously described, in some embodiments, the non-optical unit 108 of the imaging device 115 is not mechanically coupled to the optical unit of the imaging device, as illustrated in FIGS. 1B-1E. Employing any one of a variety of available communication technologies, the apparatus described herein can employ a means of wireless communication 101c between the optical unit and the non-optical unit. Such wireless means of communication include electromagnetic telecommunications, (i.e.: radio), and point-to-point, or point-to-multi-point wireless networking, or alternately, light (e.g.: infrared), magnetic, or electric fields.

In some embodiments the optical unit 120 of the imaging device 115 further comprises at least one of a filter, positional sensor, storage medium, battery, zooming motor, circuitry, power supply, processor, or housing. In still other embodiments, the optical unit of the imaging device further comprises a weight adapted to provide stability for the optical unit. In still other embodiments, the weight comprises a battery.

In some embodiments, the non-optical unit does not include a lens or a photosensor. In other embodiments, the non-optical unit of the imaging device comprises at least one of a positional sensor, storage medium, battery, motors, circuitry, power supply, processor, or housing.

In some embodiments, at least one of the first rotational axis and the second rotational axis corresponds to a pitch, roll or yaw axis of the optical unit. In other embodiments, the frame assembly is further configured to permit the optical unit to rotate about a third rotational axis. In some embodiments, the third rotational axis corresponds to at least one of a pitch, roll, or yaw axis of the optical unit.

Still further, in some embodiments, the apparatus further comprises one or more positional sensors, wherein at least one of the one or more positional sensors is configured to detect state information associated with the optical unit. In addition the apparatus further comprises a controller for generating one or more motor signals based on the state information associated with the optical unit. In some embodiments, the state information comprises translational or rotational movement information or positional information.

In still other embodiments, at least one of the positional sensors is configured to detect state information associated with the non-optical unit.

In still further embodiments, at least one of the one or more positional sensors is configured to measure movement associated with at least a pitch, roll, or yaw axis of the optical unit. In addition, at least one of the one or more positional sensors comprises an inertial sensor.

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In any of the stated embodiments, the apparatus is configured to be coupled to a movable object. A moveable object may be anything that can move relative to the earth. For example, moveable objects can be a wheeled-vehicle; a tracked-vehicle; a sliding or sledded vehicle; an aircraft; a hovercraft; a watercraft; or a spacecraft. Alternatively, a moving object can be defined as a human being; a mammal; an aquatic animal; an amphibious animal; a reptile; a bird; or an invertebrate animal. Still further, a moving object can be relatively fixed, but still capable of movement, such as a tree, pole, or even a building that may be subject to swaying or vibration due to wind or even earthquakes.

In addition, the apparatus is configured to reduce relatively more movement experienced by the optical unit caused by the movable object than the amount of movement experienced by the non-optical unit. This movement is often described as one of vibration, shock, sway, tremor, shaking, or jerking movement. In some embodiments, the apparatus for stabilizing an imaging device comprising an optical unit and a non-optical unit is configured to be handheld. More specifically, a novel aspect of the apparatus is the inherent ability to uniquely isolate the optical unit thus producing a more stable platform for vibration-free imagery. Since a large proportion of the overall weight of an imaging device is associated with components and sub-components that are not directly associated with the lens and photosensor, the apparatus is designed to provide better vibration dampening and higher response rates to the smaller and lighter components of the optical unit alone.

As stated previously, the apparatus is configured to be coupled to a movable object. In addition, the apparatus is configured to reduce relatively more movement experienced by the optical unit caused by the movable object than the amount of movement experienced by the non-optical unit. In some embodiments, the apparatus for stabilizing at least a portion of an imaging device comprising an optical unit and a non-optical unit is configured to be handheld.

Still further, in any of the preceding embodiments, the frame assembly comprises a first stage connected to and supporting the optical unit, and a second stage movable relative to the first stage and the optical unit about the first rotational axis. In addition, the frame assembly can further comprise a third stage movable relative to the second stage about the second rotational axis.

Provided herein is an apparatus for stabilizing at least a portion of an imaging device that comprises an optical unit and a non-optical unit, said apparatus comprising: a frame assembly supporting the optical unit of the imaging device, wherein the frame assembly is configured to permit rotation of the optical unit about at least a first rotational axis and a second rotational axis, and wherein the optical unit comprises at least a lens and a photosensor that is optically coupled to the lens; and a motor assembly operably connected to the frame assembly, wherein the motor assembly is configured to drive the frame assembly so as to permit rotation of the optical unit about at least the first rotational axis or the second rotational axis, and wherein the motor assembly consumes a minimum amount of energy that is less than that required to drive a frame assembly supporting the entire imaging device.

As further illustrated in FIG. 1, in a preferred embodiment, the motor assembly will preferably consume no more than one half of the amount of energy than that of a motor assembly required to drive a frame assembly supporting the entire imaging device.

Referring to the previous Example 1, the motor along each axis of a 3-axis frame assembly of the subject invention has a

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rated power of only about 2 w. An alternative illustrative embodiment for a 3-axis frame is illustrated in FIG. 2, (no imaging device shown).

Whereas by comparison, the motors required to drive the referenced 2-axis frame assembly for a comparable “compact” GoPro camera are significantly larger. The much larger motors required to drive the larger 2-axis frames require 5 w power levels for each motor along each axis. An example of larger 2-axis frame required for a comparable frame assembly supporting the entire imaging device is seen in FIG. 6.

In some embodiments the non-optical unit of the imaging device is not mechanically coupled to the apparatus. In some embodiments the optical unit and the non-optical unit are electrically coupled. In some embodiments the optical unit and the non-optical unit are movable relative to each other.

As previously described, in some embodiments, the non-optical unit of the imaging device is not mechanically coupled to the optical unit of the imaging device. Employing any one of a variety of available communication technologies, the apparatus described herein can employ a means of wireless communication between the optical unit and the non-optical unit. Such wireless means of communication include electromagnetic telecommunications, (i.e.: radio), and point-to-point, or point-to-multi-point wireless networking, or alternately, light (e.g.: infrared), magnetic, or electric fields.

In some embodiments the optical unit of the imaging device further comprises at least one of a filter, positional sensor, storage medium, battery, zooming motor, circuitry, power supply, processor, or housing. In still other embodiments, the optical unit of the imaging device further comprises a weight adapted to provide stability for the optical unit. In still other embodiments, the weight comprises a battery.

In some embodiments, the non-optical unit does not include a lens or a photosensor. In other embodiments, the non-optical unit of the imaging device comprises at least one of a positional sensor, storage medium, battery, motors, circuitry, power supply, processor, or housing.

In some embodiments, at least one of the first rotational axis and the second rotational axis corresponds to a pitch, roll or yaw axis of the optical unit. In other embodiments, the frame assembly is further configured to permit the optical unit to rotate about a third rotational axis. In some embodiments, the third rotational axis corresponds to at least one of a pitch, roll, or yaw axis of the optical unit.

Still further, in some embodiments, the apparatus further comprises one or more positional sensors, wherein at least one of the one or more positional sensors is configured to detect state information associated with the optical unit. In addition the apparatus further comprises a controller for generating one or more motor signals based on the state information associated with the optical unit. In some embodiments, the state information comprises translational or rotational movement information or positional information.

In still other embodiments, at least one of the positional sensors is configured to detect state information associated with the non-optical unit.

In still further embodiments, at least one of the one or more positional sensors is configured to measure movement associated with at least a pitch, roll, or yaw axis of the optical unit. In addition, at least one of the one or more positional sensors comprises an inertial sensor.

In some of the preceding embodiments, the apparatus is configured to be coupled to a movable object. In addition, the apparatus is configured to reduce relatively more movement experienced by the optical unit caused by the movable object than the amount of movement experienced by the non-optical

unit. In some embodiments, the apparatus for stabilizing at least a portion of an imaging device comprising an optical unit and a non-optical unit is configured to be handheld.

Still further, in some of the preceding embodiments, the frame assembly comprises a first stage connected to and supporting the optical unit, and a second stage movable relative to the first stage and the optical unit about the first rotational axis. In addition, the frame assembly can further comprise a third stage movable relative to the second stage about the second rotational axis.

In some embodiments of the apparatus, said energy is less than the amount of energy required to drive the frame assembly when the entire imaging device apparatus as a whole is supported by the frame assembly.

In some embodiments wherein an apparatus for stabilizing at least a portion of an imaging device that comprises an optical unit and a non-optical unit, and wherein the motor assembly consumes a minimum amount of energy that is less than that required to drive a frame assembly supporting the entire imaging device, said energy is less than the amount of energy required to drive the frame assembly when the entire imaging device apparatus as a whole is supported by the frame assembly.

As suggested above, at least one embodiment of the apparatus comprises a frame assembly configured to support an entire imaging device, wherein the components have been separated and are placed at different locations on the frame. For example, as shown in FIG. 1, the non-optical unit is placed on the base 107, on the Z-axis frame, whereas the optical unit is connected to the X-axis frame. In this configuration, the mass of the non-optical component can be completely isolated from the optical unit, thus allowing for a mixture of frame assembly components, with larger motors and frame base on the Z-plane, and the use of smaller configuration frame components below the Z-plane and subsequently use motors that consume less energy to drive the frame controlling only the optical unit movements. This example is only meant as one illustrative example of the numerous possible configurations and sub-configurations which are now possible.

Provided herein is an imaging device comprising an optical unit 309 which comprises at least a lens and a photosensor that is optically coupled to the lens; and a non-optical unit that is electrically coupled to the optical unit (not-shown), wherein the optical unit is movable relative to the non-optical unit via actuation of a frame assembly 300 coupled to said optical unit, as previously illustrated in FIG. 1.

In some embodiments, the non-optical unit is not mechanically coupled to the frame assembly. As shown in FIG. 3, a representative three-axis frame assembly 300 is illustrated with an optical unit 309 coupled to the X-axis 302 of the frame in a carrier bracket 308, however, the non-optical unit is remotely located somewhere off the frame. As described previously, the non-optical unit and optical unit are illustrated in a wireless communication set-up.

As with prior examples, the illustrative frame has drive motors 310, 312, 320 with positional sensors 322 and at least one controller 324 for generating one or more motor signals for driving the movement of the frame assembly of the apparatus, based on the state information generated by the sensors.

Further, as illustrated by rotational symbols  $\alpha$  and  $\beta$  the portion of the frame assembly controlling the movement of the optical unit has freedom to move in a rotation angle ( $\alpha$ ) between Z 306 (yaw) & Y 304 (roll) axes, and in non-right angle of rotation ( $\theta$ ), resulting in net attitudinal translational

movement separate from the non-optical unit, whether the non-optical unit is coupled to the frame or located remotely.

Additionally, FIG. 3 and FIG. 4 illustrate a means for alternative translational and attitudinal movement by providing additional rotation arms 314, 429, 442 and supporting arm extensions 315, 441 respectively, which further illustrate relative movement that is capable between the optical and non-optical units of the imaging device and also provide greater range of movement within the frame itself.

In some embodiments, the optical unit further comprises at least one of a filter, positional sensor, storage medium, battery, zooming motor, circuitry, power supply, processor, or housing. In other embodiments, the optical unit further comprises a weight adapted to provide stability for the optical unit. In some embodiments the weight comprises a battery.

In some embodiments, the non-optical unit does not include a lens or a photosensor. In other embodiments, the non-optical unit of the imaging device comprises at least one of a positional sensor, storage medium, battery, motors, circuitry, power supply, processor, or housing.

In some embodiments of the imaging device, the optical unit 309, is movable about a first rotational axis 302 and a second rotational axis 304 via the actuation of the frame assembly and the optical unit is movable about a third rotational axis 306 via the actuation of the frame assembly.

In other embodiments of the imaging device, the optical unit is movable about a third rotational axis via the actuation of the frame assembly and the third rotational axis corresponds to at least one of a pitch, roll, or yaw axis of the optical unit.

In still further embodiments of the imaging device, the state information associated with the optical unit is detectable by one or more positional sensors 322 and said state information associated with the optical unit is used to generate one or more motor signals via the controller 324 that drive the actuation of the frame assembly. Said state information comprises translational or rotational movement information or positional information. In addition, state information associated with the non-optical unit is detectable by one or more positional sensors.

In still further embodiments of the imaging device, at least one of the one or more positional sensors is configured to measure movement associated with at least a pitch, roll, or yaw axis of the optical unit, and at least one of the one or more positional sensors comprises an inertial sensor.

In some embodiments, the frame assembly of the imaging device is configured to be coupled to a moveable object. As illustrated in FIGS. 3 and 4 multiple fixing points 318, 418 are provided on a Z-axis base 316, as one possible location for coupling a frame assembly to a moveable object.

In some embodiments of the imaging device, the optical unit and the non-optical unit are contained within a single housing. As shown in FIG. 4, a miniaturized imaging device 459 is contained within the carrier bracket 431 and driven about a first axis with a first driving member 432 and one or more positional sensors 422. In other embodiments, the optical unit and the non-optical unit are not contained within a single housing. In this embodiment, the imaging device has a complete range of multi-axis rotational and translational movement with the ability to pivot about a first rotating axis 429 and the rotational axis of the first driving member 432. Additionally, roll motion is provided by the second drive motor and positional sensor 433, 422, with motor signal provided by controller 424. And finally, yaw motion is provided by a third drive motor 434 and positional sensor 422, allowing the imaging device to pivot about the extension arms 441, and 442.



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In still other embodiments of the imaging device **459**, the optical unit and the non-optical unit are both utilized to capture and store an image.

As shown in FIG. 5A, a representative aerial vehicle **500** is provided comprising a vehicle body **510** and an apparatus for stabilizing an imaging device attached to the vehicle body comprising: an optical unit and a non-optical unit, said apparatus comprising: a frame assembly **520** having a mounting member **525**, rotatably coupled to the optical unit of the imaging device **540**, and supporting the entire imaging device as a whole, wherein the frame assembly is configured to permit the imaging device to rotate about at least a first rotational axis **501** and a second rotational axis **502**, the optical unit comprising at least a lens **521** (not shown), and a photosensor **523** (not shown) that is optically coupled to the lens; and a motor assembly **530** coupled to the frame assembly, the motor assembly configured to directly drive the frame assembly so as to permit the optical unit to rotate about at least the first rotational axis or the second rotational axis.

Optionally, the device is configured with a third motor assembly **536** coupled to the frame assembly, the motor assembly configured to directly drive the frame assembly **570** so as to permit the optical unit **545** to rotate about a third rotational axis **503**, as illustrated in FIGS. 5B and 5C.

Provided herein is an aerial vehicle comprising a vehicle body and an apparatus for stabilizing at least a portion of an imaging device attached to the vehicle body that comprises: an optical unit and a non-optical unit, said optical unit and non-optical unit constituting the entire imaging device, said apparatus comprising: a frame assembly having a volume that is less than that of a frame assembly required to support the entire imaging device having the optical unit and the non-optical unit, wherein the frame assembly is configured to support the optical unit of the imaging device, wherein the frame assembly is configured to permit rotation of the optical unit about at least a first rotational axis and a second rotational axis, and wherein the optical unit comprises at least a lens and a photosensor that is optically coupled to the lens; and a motor assembly operably connected to the frame assembly, wherein the motor assembly is configured to drive the frame assembly so as to permit rotation of the optical unit about at least the first rotational axis or the second rotational axis. Optionally, the device is configured with a third motor assembly **536** coupled to the frame assembly, the motor assembly configured to directly drive the frame assembly **570** so as to permit the optical unit **545** to rotate about a third rotational axis **503**, as illustrated in FIGS. 5B and 5C.

Preferably, as shown in FIG. 5B, the frame assembly **570** is configured to support the optical unit **545** of the imaging device, without supporting the entire imaging device **540** as a whole, wherein the frame assembly is configured to permit the optical unit to rotate about at least a first rotational axis **501** and a second rotational axis **502**, and optionally a third rotational axis **503**, the optical unit comprising at least a lens **521** and a photosensor **523** that is optically coupled to the lens; and motor assemblies **532**, **534** coupled to the frame assembly, the motor assemblies configured to directly drive the frame assembly **570** so as to permit the optical unit **545** to rotate about at least the first rotational axis **502**, or the second rotational axis **501**. In addition, a third motor assembly **536** is coupled to the frame assembly, to permit the optical unit **545** to rotate about a third rotational axis **503**.

Provided herein is an aerial vehicle comprising a vehicle body and an apparatus for stabilizing at least a portion of an imaging device attached to the vehicle body that comprises an optical unit and a non-optical unit, said optical unit and non-optical unit constituting the entire imaging device, said apparatus

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comprising: a frame assembly supporting the optical unit of the imaging device, wherein the frame assembly is configured to permit rotation of the optical unit about at least a first rotational axis and a second rotational axis, and wherein the optical unit comprises at least a lens and a photosensor that is optically coupled to the lens; and a motor assembly operably connected to the frame assembly, wherein the motor assembly is configured to drive the frame assembly so as to permit rotation of the optical unit about at least the first rotational axis or the second rotational axis, and wherein the motor assembly consumes a minimum amount of energy that is less than that required to drive a frame assembly supporting the entire imaging device.

In some embodiments of the aerial vehicle **500**, said vehicle comprises an engine **555** configured to drive movement of said aerial vehicle. In some embodiments, the engine is configured within said vehicle body. In some embodiments, the engine is configured as a component of a rotor assembly **550**.

According to another aspect of the present invention the apparatus for stabilizing at least a portion of an imaging device also comprises shock absorbers **571** such as illustrated in FIG. 5B. Shock absorbers can be placed strategically on the frame, preferably between the frame and the moving vehicle, at the mounting surface, to insulate the imaging device, or more importantly, the optical unit from vibration, shock, sway, tremor, shaking, or jerking movement.

In some embodiments, the aerial vehicle is an unmanned aerial vehicle capable of controlled flight without requiring an occupant of the aerial vehicle.

In some embodiments, the aerial vehicle comprises one or more blades **557** configured to rotate to provide lift to the unmanned aerial vehicle.

In some embodiments of the aerial vehicle, the non-optical unit is supported by the vehicle body without being supported by the frame assembly. As illustrated in prior examples, and again in FIG. 5B, or FIGS. 1B-1E, the optical unit and non-optical units can be physically separated and communicate by either tethered (wired) **101** or wireless communication means **101c**.

Provided herein is a method of stabilizing at least a portion of an imaging device that comprises an optical unit and a non-optical unit, said method comprising: supporting the optical unit of the imaging device using a frame assembly without supporting the entire imaging device as a whole, as illustrated in FIGS. 1A and 5B, wherein the frame assembly is configured to permit rotation of the optical unit about at least a first rotational axis and a second rotational axis, and wherein the optical unit comprises at least a lens and a photosensor that is optically coupled to the lens; and driving the frame assembly using a motor assembly operably connected to the frame assembly, thereby causing rotation of the optical unit about at least the first rotational axis or the second rotational axis.

In some embodiments of the stabilizing method, the optical unit and the non-optical unit are electrically coupled to each other.

In some embodiments of the stabilizing method, the optical unit **120**, **540** further comprises at least one of a filter, positional sensor, storage medium **105**, battery **104**, zooming motor, circuitry **103**, power supply, processor, or housing. In other embodiments of the method, the optical unit further comprises a weight adapted to provide stability for the optical unit. In some embodiments, the weight comprises a battery. In still further embodiments, the battery is configured to provide power necessary for operation of an aerial vehicle or the imaging device.

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In some embodiments of the stabilizing method, the non-optical **108** unit does not include a lens or a photosensor. In other embodiments of the stabilizing method, the non-optical unit comprises at least one of a positional sensor, storage medium **105**, power supply, battery **104**, motors, circuitry **103**, display, processor, or housing **109**.

In still other embodiments of the stabilizing method, at least one of the first rotational axis and the second rotational axis corresponds to a pitch, roll, or yaw axis of the optical unit. In other embodiments, the method further comprises driving the frame assembly using the motor assembly, thereby causing rotation of the optical unit about a third rotational axis. Still further the method wherein the third rotational axis corresponds to at least one of a pitch, roll or yaw axis of the optical unit.

In yet other embodiments of the stabilizing method, said method comprises receiving a signal from at least one positional sensor for indicative of an inclination angle of the non-optical unit and/or the optical unit in order to correct an inclination angle of the optical unit. In still other embodiments, said method further comprises reducing more movement experienced by the optical unit than the amount of movement experienced by the non-optical unit. In some embodiments of the method, said movement comprises at least one of vibration, shock, sway, tremor, shaking, or jerking movement.

In any of the preceding embodiments of the stabilizing method, said method further comprises capturing and storing an image using both the optical unit **120** and non-optical unit **108**.

Provided herein is a method of stabilizing at least a portion of an imaging device that comprises an optical unit and a non-optical unit, said optical unit and non-optical unit constituting the entire imaging device, said method comprising: supporting the optical unit of the imaging device using a frame assembly, the frame assembly having a volume that is less than that of a frame assembly required to support the entire imaging device having the optical unit and the non-optical unit, wherein the frame assembly is configured to permit rotation of the optical unit about at least a first rotational axis and a second rotational axis, and wherein the optical unit comprises at least a lens and a photosensor that is optically coupled to the lens; and driving the frame assembly using a motor assembly operably connected to the frame assembly, thereby causing rotation of the optical unit about at least the first rotational axis or the second rotational axis.

In some embodiments of the stabilizing method, the optical unit and the non-optical unit are electrically coupled to each other.

In some embodiments of the stabilizing method, the optical unit further comprises at least one of a filter, positional sensor, storage medium, battery, zooming motor, circuitry, power supply, processor, or housing. In other embodiments of the method, the optical unit further comprises a weight adapted to provide stability for the optical unit. In some embodiments, the weight comprises a battery **104**. In still further embodiments, the battery is configured to provide power necessary for operation of an aerial vehicle or the imaging device.

In some embodiments of the stabilizing method, the non-optical **108** unit does not include a lens or a photosensor. In other embodiments of the stabilizing method, the non-optical unit comprises at least one of a positional sensor, storage medium, power supply, battery, motors, circuitry, display, processor, or housing.

In still other embodiments of the stabilizing method, at least one of the first rotational axis and the second rotational axis corresponds to a pitch, roll, or yaw axis of the optical

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unit. In other embodiments, the method further comprises driving the frame assembly using the motor assembly, thereby causing rotation of the optical unit about a third rotational axis. Still further the method wherein the third rotational axis corresponds to at least one of a pitch, roll or yaw axis of the optical unit.

In yet other embodiments of the stabilizing method, said method comprises receiving a signal from at least one positional sensor for indicative of an inclination angle of the non-optical unit and/or the optical unit in order to correct an inclination angle of the optical unit. In still other embodiments, said method further comprises reducing more movement experienced by the optical unit than the amount of movement experienced by the non-optical unit. In some embodiments of the method, said movement comprises at least one of vibration, shock, sway, tremor, shaking, or jerking movement.

In any of the preceding embodiments of the stabilizing method, said method further comprises capturing and storing an image using both the optical unit and non-optical unit.

Provided herein is a method of stabilizing at least a portion of an imaging device that comprises an optical unit and a non-optical unit, said method comprising: supporting the optical unit of the imaging device using a frame assembly, wherein the frame assembly is configured to permit rotation of the optical unit about at least a first rotational axis and a second rotational axis, and wherein the optical unit comprises at least a lens and a photosensor that is optically coupled to the lens; and driving the frame assembly using a motor assembly operably connected to the frame assembly, the motor assembly consuming a minimum amount of energy that is less than that required to drive a frame assembly supporting the entire imaging device, thereby causing rotation of the optical unit about at least the first rotational axis or the second rotational axis.

In some embodiments of the stabilizing method, the optical unit and the non-optical unit are electrically coupled to each other.

In some embodiments of the stabilizing method, the optical unit further comprises at least one of a filter, positional sensor, storage medium, battery, zooming motor, circuitry, power supply, processor, or housing. In other embodiments of the method, the optical unit further comprises a weight adapted to provide stability for the optical unit. In some embodiments, the weight comprises a battery. According to another aspect of the present invention, the battery is configured to provide power necessary for operation of an aerial vehicle or the imaging device.

In some embodiments of the stabilizing method, the non-optical unit does not include a lens or a photosensor. In other embodiments of the stabilizing method, the non-optical unit comprises at least one of a positional sensor, storage medium, power supply, battery, motors, circuitry, display, processor, or housing.

In still other embodiments of the stabilizing method, at least one of the first rotational axis and the second rotational axis corresponds to a pitch, roll, or yaw axis of the optical unit. In other embodiments, the method further comprises driving the frame assembly using the motor assembly, thereby causing rotation of the optical unit about a third rotational axis. Still further the method wherein the third rotational axis corresponds to at least one of a pitch, roll or yaw axis of the optical unit.

In yet other embodiments of the stabilizing method, said method comprises receiving a signal from at least one positional sensor for indicative of an inclination angle of the non-optical unit and/or the optical unit in order to correct an

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inclination angle of the optical unit. In still other embodiments, said method further comprises reducing more movement experienced by the optical unit than the amount of movement experienced by the non-optical unit. In some embodiments of the method, said movement comprises at least one of vibration, shock, sway, tremor, shaking, or jerking movement.

In any of the preceding embodiments of the stabilizing method, said method further comprises capturing and storing an image using both the optical unit and non-optical unit.

Provided herein is a method of stabilizing at least a portion of an imaging device, said method comprising providing an optical unit comprising at least a lens and a photosensor that is optically coupled to the lens; electrically coupling a non-optical unit to the optical unit; and moving the optical unit relative to the non-optical unit via actuation of a frame assembly coupled to said optical unit.

In some embodiments of the stabilizing method, the optical unit further comprises at least one of a filter, positional sensor, storage medium, battery, zooming motor, circuitry, power supply, processor, or housing. In other embodiments of the method, the optical unit further comprises a weight adapted to provide stability for the optical unit. In some embodiments, the weight comprises a battery. In still further embodiments, the battery is configured to provide power necessary for operation of an aerial vehicle or the imaging device.

In some embodiments of the stabilizing method, the non-optical unit does not include a lens or a photosensor. In other embodiments of the stabilizing method, the non-optical unit comprises at least one of a positional sensor, storage medium, power supply, battery, motors, circuitry, display, processor, or housing.

In still other embodiments of the stabilizing method, at least one of the first rotational axis and the second rotational axis corresponds to a pitch, roll, or yaw axis of the optical unit. In other embodiments, the method further comprises driving the frame assembly using the motor assembly, thereby causing rotation of the optical unit about a third rotational axis. Still further the method wherein the third rotational axis corresponds to at least one of a pitch, roll or yaw axis of the optical unit.

In yet other embodiments of the stabilizing method, said method comprises receiving a signal from at least one positional sensor for indicative of an inclination angle of the non-optical unit and/or the optical unit in order to correct an inclination angle of the optical unit. In still other embodiments, said method further comprises reducing more movement experienced by the optical unit than the amount of movement experienced by the non-optical unit. In some embodiments of the method, said movement comprises at least one of vibration, shock, sway, tremor, shaking, or jerking movement.

In any of the preceding embodiments of the stabilizing method, said method further comprises capturing and storing an image using both the optical unit and non-optical unit.

Provided herein is an aerial vehicle comprising a vehicle body and a frame assembly connected to said vehicle body, wherein said frame assembly comprises a battery attached thereto and said frame assembly is configured to hold and stabilize an imaging device having an optical unit, and wherein the battery is attached to the assembly at a location separate from that of the imaging device, and wherein the battery is configured to provide power for operation of the aerial vehicle or the imaging device.

In some embodiments, the battery is configured to provide power for operation of the aerial vehicle. In some embodi-

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ments the battery has a weight that provides stability to said optical unit of said imaging device.

While preferred embodiments of the present invention have been shown and described herein, it will be obvious to those skilled in the art that such embodiments are provided by way of example only. Numerous variations, changes, and substitutions will now occur to those skilled in the art without departing from the invention. It should be understood that various alternatives to the embodiments of the invention described herein may be employed in practicing the invention. It is intended that the following claims define the scope of the invention and that methods and structures within the scope of these claims and their equivalents be covered thereby.

What is claimed is:

1. An aerial vehicle comprising: (a) a central body and (b) an apparatus for stabilizing at least a portion of an imaging device, said imaging device comprising an optical unit and a non-optical unit, and said optical unit and said non-optical unit constituting the entire imaging device, said apparatus comprising:

a frame assembly supporting the optical unit of the imaging device without supporting the entire imaging device as a whole, wherein said optical unit comprises a lens and a photosensor, wherein the frame assembly comprises: (A) a first frame member that supports a compact unit comprising: (1) an inertial measurement unit and (2) the optical unit from a single side without supporting an opposing side of the compact unit, and (B) a second frame member that bears weight of the first frame member, and wherein the frame assembly is configured to permit rotation of the compact unit about at least a first rotational axis and a second rotational axis;

a motor assembly operably connected to the frame assembly, wherein the motor assembly is configured to drive the frame assembly in response to a signal provided by the inertial measurement unit so as to permit rotation of the optical unit and the inertial measurement unit about at least the first rotational axis or the second rotational axis; and

a separate housing (1) not supported by the frame assembly and (2) containing therein one or more non-optical components selected from the group consisting of a display and a power supply for powering the photosensor, wherein the power-supply for powering the photosensor, a processor to process the image captured by the photosensor and a memory device to store the image, are not supported by the frame assembly and do not rotate with the optical unit to reduce the enemy required by the motor assembly,

wherein the second frame member is also (1) movable relative to the first frame member, and (2) movable relative to the separate housing about at least one axis of rotation.

2. The aerial vehicle of claim 1, wherein the frame assembly having a volume that is less than that of a frame assembly required to support the entire imaging device having the optical unit and the non-optical unit.

3. The aerial vehicle of claim 1, wherein the second frame member of the frame assembly is rotatably coupled to the first frame member on the pitch axis, and (3) a third frame member rotatably coupled to the second frame member on the roll axis and configured to rotate relative to the movable object about the yaw axis, and

wherein the motor assembly comprises: (1) a first motor configured to drive movement of the first frame member

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relative to the second frame member about the pitch axis, (2) a second motor configured to drive movement of the second frame member relative to the third frame member about the roll axis, and (3) a third motor configured to drive movement of the third frame member relative to the movable object about the yaw axis.

4. The aerial vehicle of claim 1, wherein the non-optical unit is electrically coupled to the optical unit.

5. The aerial vehicle of claim 1, wherein the non-optical unit of the imaging device is not mechanically coupled to the apparatus.

6. The aerial vehicle of claim 1, wherein the optical unit and the non-optical unit are electrically coupled and movable relative to each other.

7. The aerial vehicle of claim 1, wherein the non-optical unit does not include a lens or a photosensor.

8. The aerial vehicle of claim 1, wherein at least one of the first rotational axis or the second rotational axis corresponds to a roll axis of the optical unit.

9. The aerial vehicle of claim 1, wherein the frame assembly is further configured to permit the optical unit to rotate about a third rotational axis corresponding to one of a pitch, roll, or yaw axis of the optical unit.

10. The aerial vehicle of claim 1, wherein the inertial measurement unit is configured to detect translational movement, rotational movement, or position of the optical unit.

11. The aerial vehicle of claim 1, wherein the display is configured to display images captured using the optical unit is not supported by the frame assembly and does not rotate with the optical unit.

12. The aerial vehicle of claim 10, wherein the inertial measurement unit comprises an inertial sensor.

13. The aerial vehicle of claim 1, wherein the frame assembly is freely rotatable within a range of 360 degrees over at least one axis.

14. The aerial vehicle of claim 1 wherein the first frame member is connected to the optical unit without movable components, and the second frame member is movable relative to the first frame member about the first rotational axis.

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15. The aerial vehicle of claim 14 wherein the frame assembly further comprises a third frame member movable relative to the second frame member about the second rotational axis.

16. The aerial vehicle of claim 1, wherein amount of energy required by the motor assembly to drive the frame assembly is less than that required when the entire imaging device apparatus as a whole is supported by the frame assembly.

17. The aerial vehicle of claim 4, wherein the non-optical unit does not include a lens or a photosensor, and wherein the non-optical unit is not mechanically coupled to the frame assembly.

18. The aerial vehicle of claim 4, wherein a display screen configured to display images captured using the optical unit is not supported by the frame assembly, and the display screen does not rotate with the optical unit.

19. The aerial vehicle of claim 4, wherein the optical unit is movable about the a first rotational axis and the a second rotational axis via the actuation of the frame assembly, wherein the at least one of the first rotational axis or the second rotational axis corresponds to a pitch, roll or yaw axis of the optical unit.

20. The aerial vehicle of claim 4, wherein the optical unit is movable about a third rotational axis, wherein the third rotational axis corresponds to one of a pitch, roll, or yaw axis of the optical unit.

21. The aerial vehicle of claim 4, wherein the inertial measurement unit is configured to detect translational movement, rotational movement, or position of the optical unit.

22. The method of stabilizing at least the portion of the imaging device that comprises the optical unit and the non-optical unit, said method comprising:

providing the aerial vehicle of claim 1;  
supporting the compact unit of the imaging device using the frame assembly without supporting the entire imaging device as a whole; and  
driving the frame assembly using the motor assembly.

23. The aerial vehicle of claim 8, wherein the roll axis of the optical unit is configured to intersect the optical unit.

\* \* \* \* \*

UNITED STATES PATENT AND TRADEMARK OFFICE  
**CERTIFICATE OF CORRECTION**

PATENT NO. : 9,277,130 B2  
APPLICATION NO. : 14/134375  
DATED : March 1, 2016  
INVENTOR(S) : Tao Wang et al.

Page 1 of 1

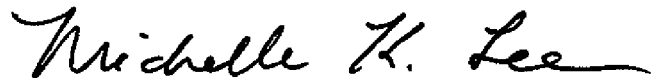
It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

In the Claims;

Column 28, Lines 6-7, Claim 16 delete “apparatus”

Column 28, Line 29, Claim 22 delete “The method” and replace with “A method”

Signed and Sealed this  
Second Day of August, 2016

A handwritten signature in black ink, reading "Michelle K. Lee". The signature is fluid and cursive, with the first letters of each name being capitalized and prominent.

Michelle K. Lee  
*Director of the United States Patent and Trademark Office*